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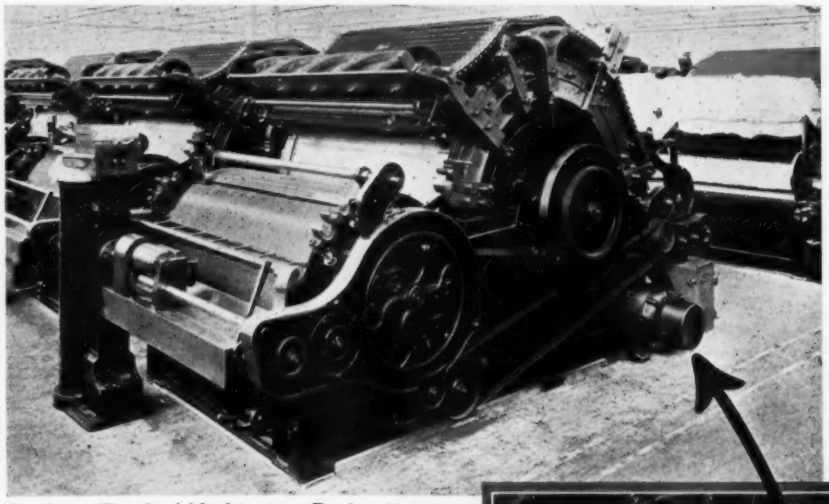

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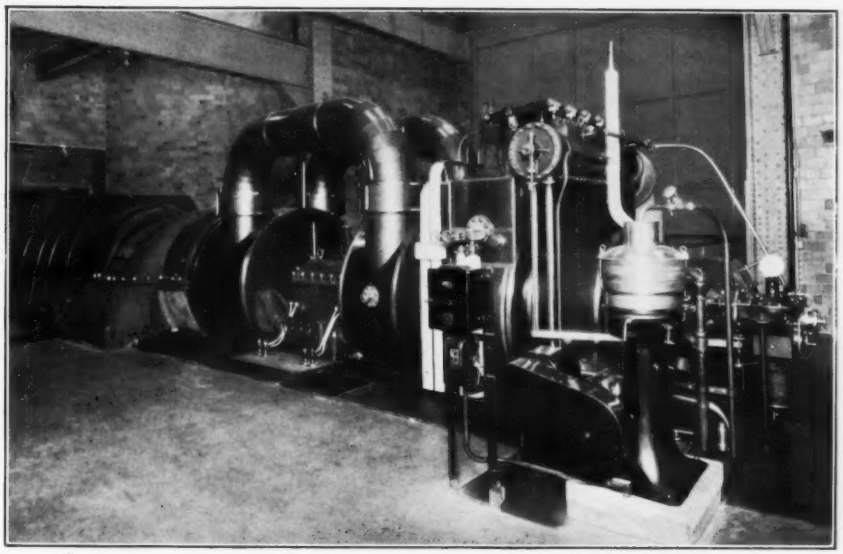

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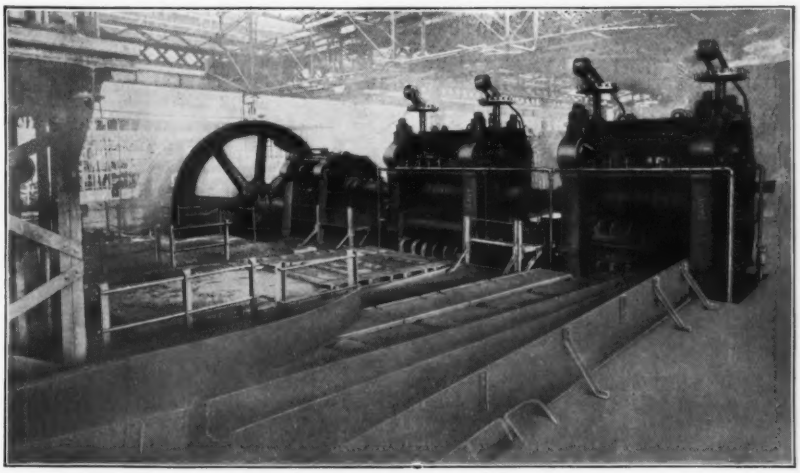

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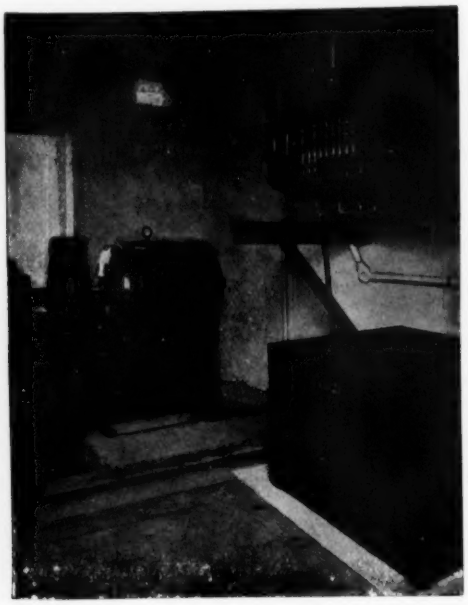

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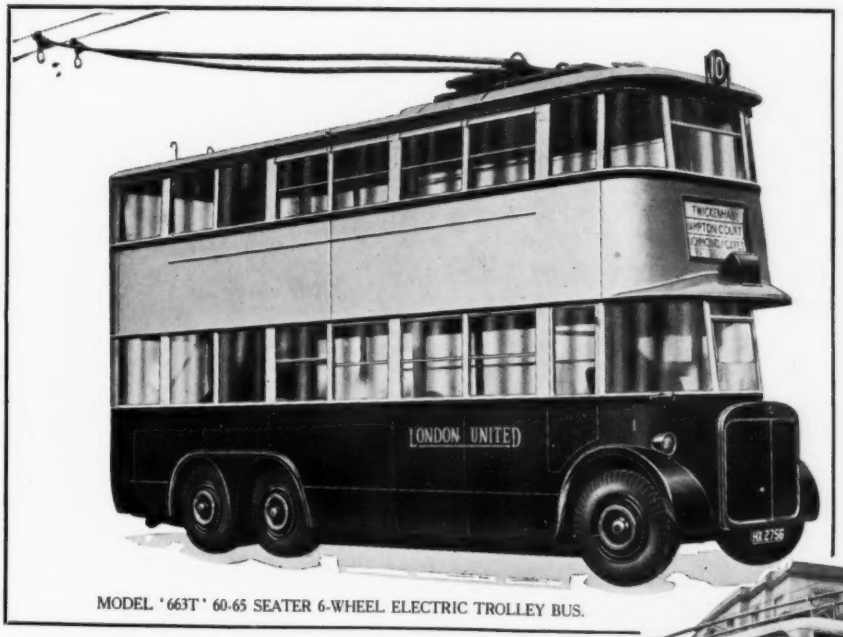

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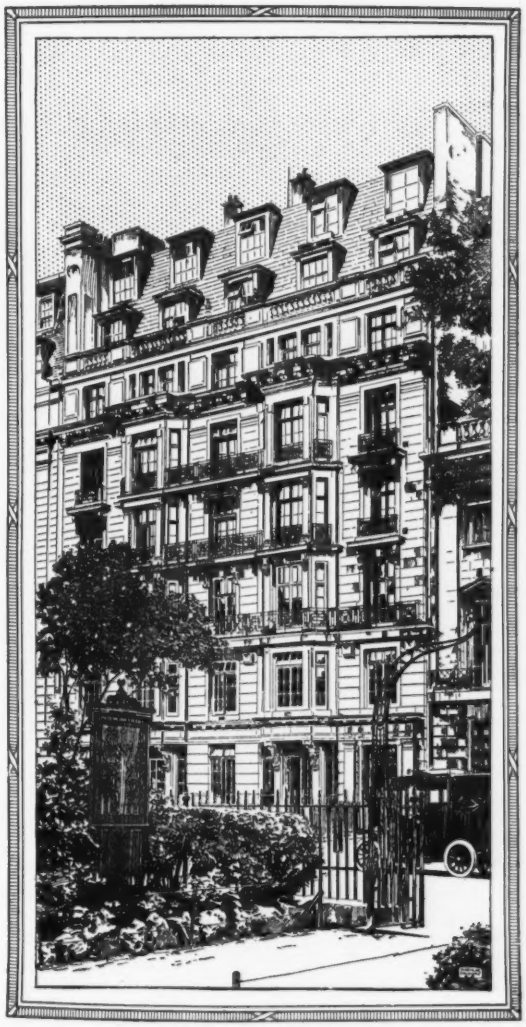

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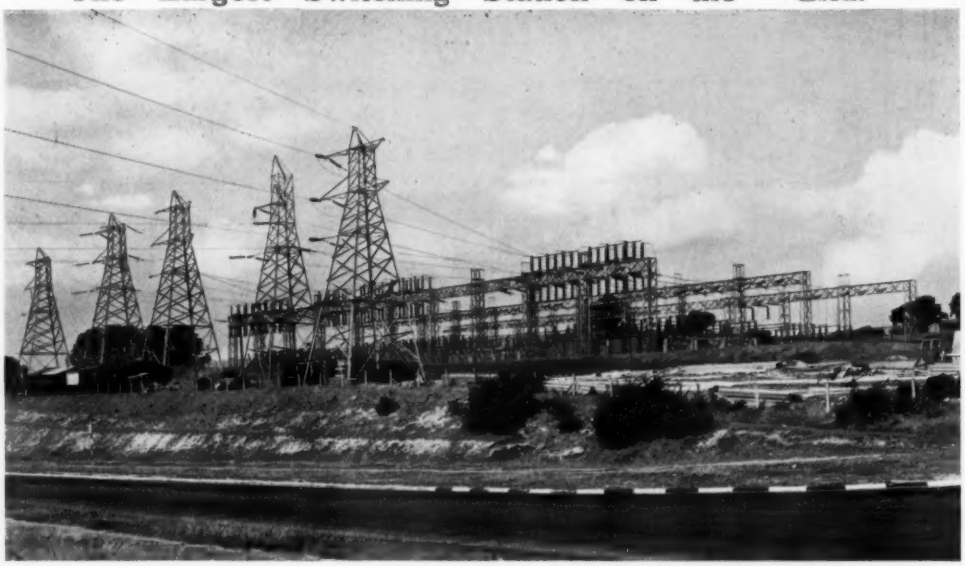

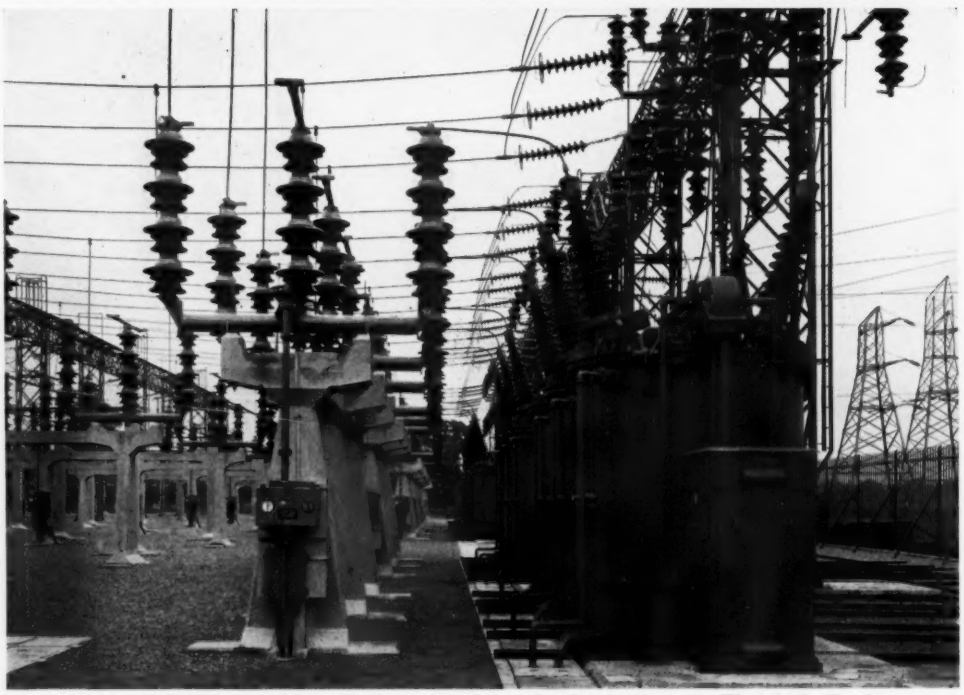

Swanscombe 132 kV. Switching Station, visited by the Institution of Electrical Engineers on September 24th, is the largest and most important interconnection point in the country. It is one of thirteen stations in the S.E. England scheme of the Central Electricity Board that are being equipped by The English Electric Company. (*See page 176*).

The English Electric Journal

Vol. V. No. 7 SEPTEMBER, 1931 One Shilling.

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All Communications respecting Editorial Contents should be addressed to THE EDITOR, THE ENGLISH ELECTRIC JOURNAL, THE ENGLISH ELECTRIC COMPANY LIMITED, STAFFORD.

EDITORIAL.

We think it much to the credit of our country that in spite of the anxieties and preoccupations of the present time, it determined that the Centenary of Faraday's discovery of the Dynamo-Electric Principle should be celebrated in an adequate and becoming manner. Not only have our Engineering Institutions and learned Societies held meetings and receptions in honour of Faraday, but the public generally have joined in the celebrations and flocked to the illuminations and to the exhibition at the Albert Hall. They were proud that it was an Englishman who made this great discovery, the discovery from which has sprung the Electrical Age in which we are now living; just as in Victorian times they honoured those other Englishmen, James Watt and Robert Stephenson, who were the precursors of the Age of Steam. In these times of difficulty and stress it is heartening to us to "praise famous men" and to remember the great tradition that we have inherited.

Among the places of special Engineering interest to which visits were

arranged by the Institution of Electrical Engineers in the course of the recent celebrations, were the Broadcasting Station at Brookman's Park where our large 12,000-volt machines mark a real advance in extra-high-tension direct-current work, the Post Office Tube with its entirely special system of automatic traction which we have devised in collaboration with the Post Office Engineers, and to the Swanscombe Switching Station where we have installed the largest switching equipment on the "Grid" system. A visit to the Works of Messrs. Siemens Bros., which had been arranged, did not take place owing to the itinerary of which it formed part having been cancelled. Visitors would have seen there a high-voltage testing equipment which the Company had manufactured.

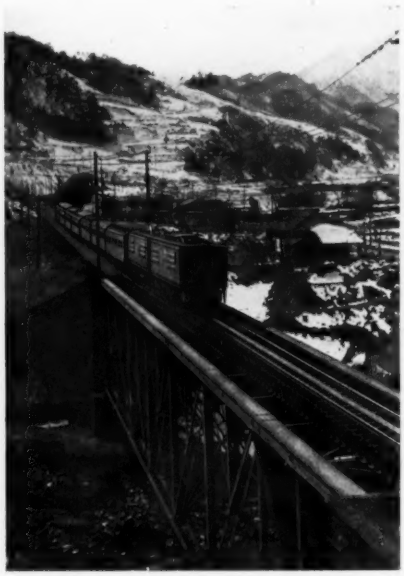
These installations are proofs of the service which our Company in its own sphere has been able to render in making available still greater benefits from electrical science. Our chief tradition is to give that whole-hearted service which marked the founders of our component firms, and it is our aim and hope to be worthy successors to them, so that over and above the merits of our products, we may be "distinguished by service."

In this issue we record the addition of steel-tank mercury arc rectifiers to the Company's long list of products. The design now described has behind it ten years of practical operation and experience, and our friends may rest assured that this product, too, carries with it the full measure of "English Electric" service.

1,500-volt Direct-current Locomotives operating on a difficult route in Japan.

Early this year an interesting section of the Imperial Government Railways was reopened after conversion to electric working. The Chuo (or Central) line connects Iidamachi station, Tokyo, with Kofu City, about 80 miles away, and runs through very hilly country. The average grade is 2·5% and a large proportion of the mileage is through tunnels.

Each train is hauled by two "English Electric" locomotives in multiple-unit operation. The illustration shows a train running over the No. 1 Katsuragawa bridge between Otsuki and Hatsukari.



Steel-Tank Mercury Rectifiers.

The English Electric Company have completed arrangements for the manufacture and marketing of a comprehensive range of rectifiers of the steel-tank type. These will be made under licence from Messrs. Siemens-Schuckertwerke A.G. and with their close technical co-operation. The S.S.W. rectifier is recognised as one of the most successful designs, and many hundreds have been put into service during the past ten years. "English Electric" rectifiers will be made at Stafford Works, and enquiries should be sent there or to any of the Company's branch offices.

The above announcement, published in the Technical Press a few weeks ago, was an indication that the Company recognises the importance of the mercury rectifier in the future development of power distribution, and also that it has taken steps to place at the disposal of its customers a well-tried design that has been in successful service for over ten years.

Up to the close of the war, the conversion of alternating current to direct current was carried out almost exclusively by rotating machines. But the comparatively high losses and the considerable maintenance and running charges, as well as the high capital expenditure on buildings and foundations that are associated with such plant, led operating engineers and manufacturers to explore the possibilities of developing more economical methods of conversion. They have always looked upon the transformer as an ideal type of apparatus, one in which there are no moving parts and which, therefore, requires the least possible maintenance, supervision, and expenditure for its accommodation, and it was natural that any new type of converting apparatus would depend largely for its success upon having characteristics that would place it on the same footing as the transformer in these respects.

Fig. 1. 3,000 kW. Rectifier in an 800-volt Traction Substation.

The nearest approach to these ideal qualities that has yet been achieved is the mercury rectifier, and it is not surprising that this remarkable apparatus has become, within a comparatively short time, a powerful competitor of the older types of converting plant.

The novelty of the mercury rectifier is not, however, so much one of principle as of the method of applying principles that were already well known and utilised in other forms. It combines with the rectification properties of the electric arc, a self-acting phase commutation principle, and is, therefore, in effect, a switching device, as opposed to a machine in which the process of conversion involves the transfer of power mechanically or by electro-dynamic action, or by both means, from the A.C. side to the D.C. side. This distinction is sometimes overlooked when comparing the mercury rectifier with rotating converting plant, but it is important because it leads to the rating of the new apparatus being based almost entirely on its current capacity alone, largely irrespective of the voltage; in other words, the kilowatts output of a given size of rectifier is, within limits, proportional to the voltage.

As will be explained more fully later, the rectifier is a " series " apparatus in which there is a relatively small voltage drop, and correspondingly a low loss.

The advantages of the steel-tank rectifier, in comparison with other types of converting plant, may be summarised as follows :—

1. High and practically constant efficiency between about 1/3 and 5/4 of normal full load.
2. Small no-load losses and consequent high economy at low load-factors.
3. Excellent performance at D.C. pressures from 500 volts up to the highest required for commercial purposes.
4. Low maintenance and operating costs.
5. Negligible depreciation.
6. Simple installation without expensive foundations.
7. Not susceptible to damage by short-circuits.
8. No synchronising needed and therefore unaffected by disturbances on A.C. system.
9. High momentary overload capacity.
10. Can be started up in a few seconds.
11. Silent operation.
12. Ease and economy of fully automatic or remote supervisory control.

The success of the " English Electric " type of rectifier is due to the proved reliability, simplicity and economy that have been attained by giving the most careful attention to every detail of design and manufacture, both of the main apparatus and of its auxiliaries. In connection with the latter it is of interest to recall that the firm which has been responsible for developing this design is one of the oldest and most experienced makers of high-vacuum exhausters. A particularly effective and durable form of vacuum seal has been developed that has advantages over other types, especially over those in which mercury is used. The problem of " back-firing " has been carefully studied, and the rectifier has been rendered largely immune from this occurrence by careful design of the internal cooling system and the anode structures ; if a " back-fire " occurs it has no serious effect upon the apparatus.

As will be seen from the illustrations, the whole of the equipment is assembled in a very practical manner as a self-contained unit that can be moved with comparatively little trouble. All the electrical and water connections are readily accessible.

The field of application is continually extending, and while the rectifier has special advantages where a direct-current supply is required at high voltage, as in traction systems, and for wireless telegraphy and broadcasting purposes, it is being used also for municipal and industrial power service, and in the electrochemical and other special industries.

As will be seen from the curve of Fig. 2, the economy of the rectifier is most pronounced at high D.C. voltages. At 1,500 volts it is already more efficient than rotary converting plant, while considerations of first cost and floor space give it further advantage. At 3,000 volts and above the superiority is very marked. Broadly speaking, the merits of the steel-tank rectifier become prominent for units handling 500 kW. or more at pressures of 500 volts and above. Units for traction service are in operation up to 3,000 volts, and for radio stations up to 20,000 volts. The

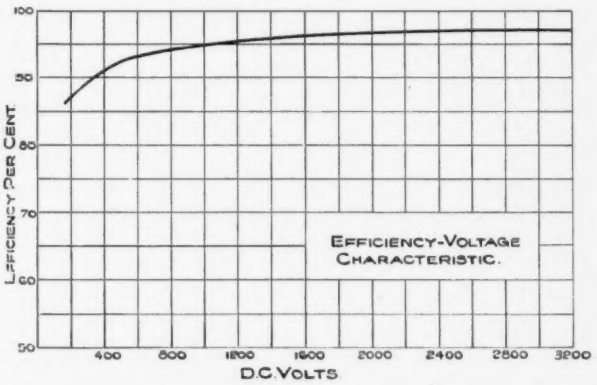
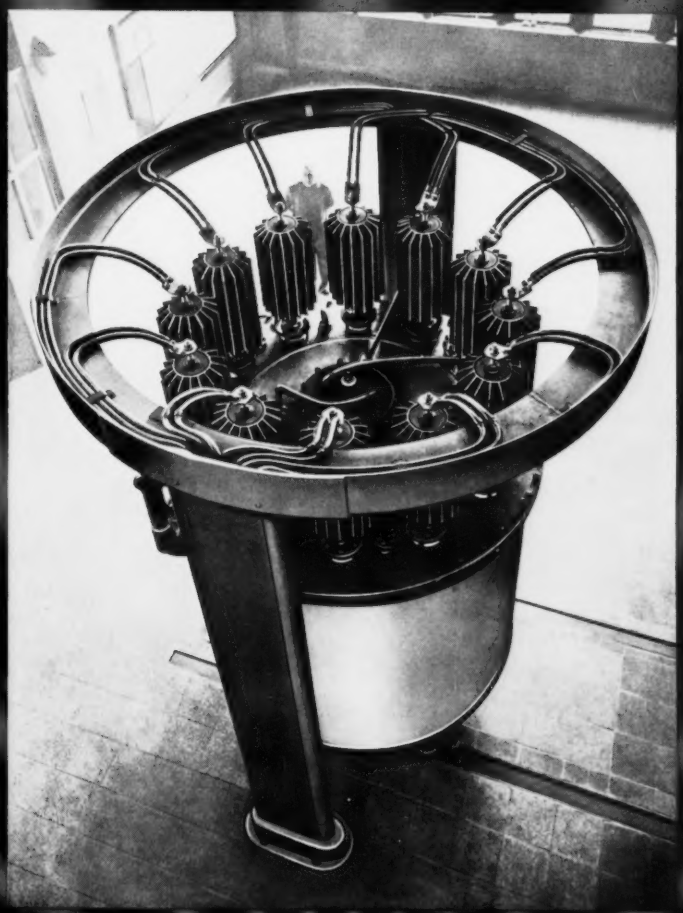


Fig. 2. Efficiency of Rectifiers as a function of the D.C. working pressure.

MERCURY-ARC RECTIFIERS



THE ENGLISH ELECTRIC COMPANY LTD

largest rectifier so far built is capable of a continuous output of 16,000 amperes at 500 volts, whilst D.C. pressures of the order of 30,000 volts have been obtained.

Fig. 3 shows the operating characteristics of a 2,000 kW. rectifier for a D.C. pressure of 1,650 volts.

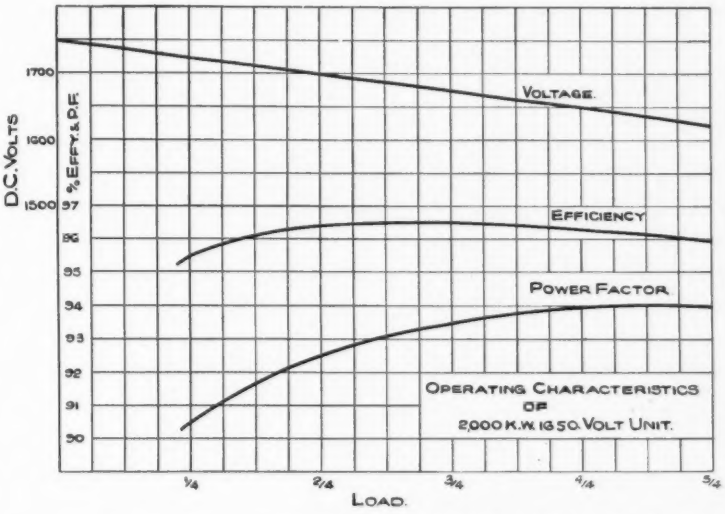


Fig. 3. Operating Characteristics of 2,000 kW., 1,650-volt Rectifier.

A mercury rectifier consists essentially of an air-tight chamber exhausted to a high degree of vacuum and containing a number of solid anodes situated symmetrically above a pool of mercury that forms the cathode. Rectification is effected by the fundamental valve action of the arc produced by maintaining the cathode in a state of electron emission, while preventing the anodes from attaining that state. In practice the A.C. supply is always a three-phase one, and a transformer feeds the rectifier at a voltage corresponding to the D.C. pressure required; as in the case of a rotary convertor, there is a definite relation between the electrical quantities on the A.C. and D.C. sides. Instead of using as the secondary winding on the transformer a three-phase winding that is taken to three anodes on the rectifier, it is the practice to use a six-phase arrangement with "English Electric" equipment and to employ interphase transformers for ensuring the best utilisation of the transformer winding, and enabling the rectifier anodes to operate under the most favourable conditions with a consequent increase in the overload capacity.

In addition to the vacuum chamber which contains the cathode, the anodes and a cooling system, there are two exhausters, and apparatus for measuring the degree of vacuum and the temperature.

Fig. 4 shows diagrammatically the arrangement of the rectifier, and it will be seen that the vacuum chamber is surrounded by a water circulation space. This water space is formed by a cylindrical tank of boiler plate which constitutes the main structural member of the rectifier to support the vacuum chamber and the accessory apparatus. The vacuum chamber is constructed of a special quality of steel that has been found to resist the action of mercury vapour and to facilitate the maintenance of a good vacuum; all the seams are carefully welded to ensure that they are absolutely air-tight.

At the base of the vacuum chamber is the cathode, consisting of a steel vessel that contains mercury and has a space on its under side for the circulation of cooling water. The cathode is insulated from the body of the vacuum chamber for the reason that if the latter were at the same potential as the cathode, the arc would tend to wander to the walls of the chamber; any tendency of the arc to leave the mercury cathode is prevented by fitting a quartz cylinder of suitable height in the cathode container. During the operation of the rectifier, vaporisation of the mercury cathode is continuous, and it is important that the vaporised mercury, after condensation by the cooling system, should return to the cathode pool without producing any tendency for the "cathode spot" to be diverted from

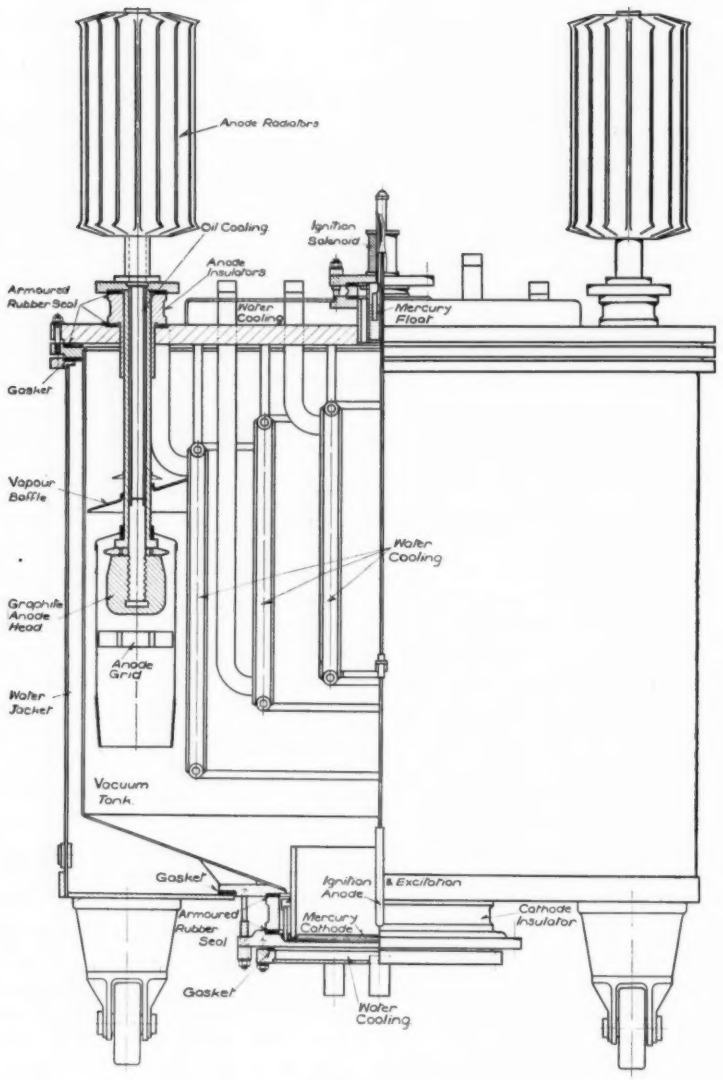


Fig. 4. Diagrammatic Section of "English Electric" Steel-Tank Mercury Rectifier.

the main pool of mercury. The arrangement of the quartz cylinder just referred to ensures this, but for greater security the return path of the mercury is " baffled," in order to hinder the formation of a cathode spot on the annular surface of the mercury outside the quartz cylinder.

For the anode tips of mercury rectifiers either iron or graphite may be used, but experience has shown that the special grade of graphite used in " English Electric " rectifiers gives the best results, as it is not liable to cause condensation of the mercury on its surface, and it withstands the thermal and mechanical stresses that arise ; with this material no preheating of the anodes is necessary when bringing the rectifier into operation.

The entire anode structure is designed from the standpoint of minimising the occurrence of " back-fires " and of withstanding the stresses that arise during heavy overloads. The anode head is screwed on to a solid iron support welded to a steel tube which passes through an insulator in the cover of the vacuum chamber ; the upper end of this tube or shank terminates in a flange to which the anode radiator and cable terminal is bolted. The shank is protected by insulation down to the anode head. In order to prevent the condensed mercury vapour coming into contact with the anode the latter is surrounded by a cylindrical anode sheath of special iron, and a deflecting hood is fitted above the sheath to direct the condensing mercury on to the wall of the chamber. The action of the insulated sheath in helping to maintain the space charge at the anode is assisted by a metal grid supported in the sheath.

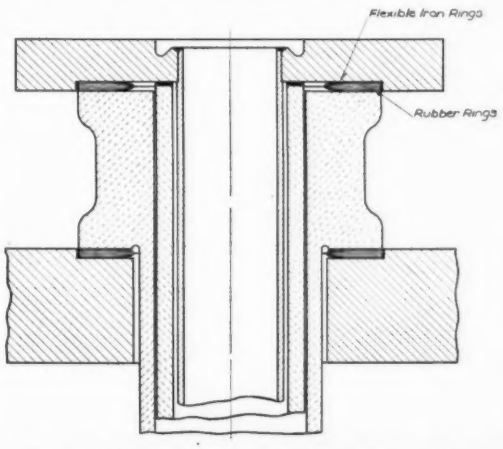


Fig. 5. Diagram showing the design of vacuum seal employed.

An important feature in the operation of a mercury rectifier is the permanence of the cathode due to the continual return to it of the mercury that is vaporised by the arc. For the effective condensation of the vapour a system of concentric cylindrical coolers is supported from the cover of the vacuum chamber in the space within the ring of anodes, and the cover and walls are cooled by the water circulation outside them. These arrangements ensure rapid condensation and a definite circulation of the vapour, and consequently give that good protection of the anode space that is so important for reliable service. A diagram of the cooling system is shown in Fig. 6. The flow of cooling water required is small, corresponding, in fact, to the low magnitude of the losses, and amounts, in the case of a 1,000-ampere unit on full load, to about 140 gallons of water per hour at an inlet temperature of 60 deg. F.

It is well known that one of the most important details of a mercury rectifier is the sealing in a thoroughly air-tight and durable manner of the unavoidable joints in the walls of the vacuum chamber. These comprise the main cover, the anode inlets and the opening for the cathode. There are obvious difficulties in devising a seal that is both effective and permanent under the influence of a very high vacuum and exposure to mercury vapour, and which is at the same time free from material that will exude vapour of any kind.

The form of seal employed in " English Electric " rectifiers has proved to be thoroughly efficient from these points of view ; a diagram of the arrangement is shown in Fig. 5. It is, in effect, a wide ring of high-quality and specially treated rubber, reinforced in a gas-tight manner on the vacuum side by a flexible iron V-ring. By virtue of its simple design this joint greatly facilitates erection or dismantling, and it contributes largely to the robustness that is characteristic of these rectifiers.

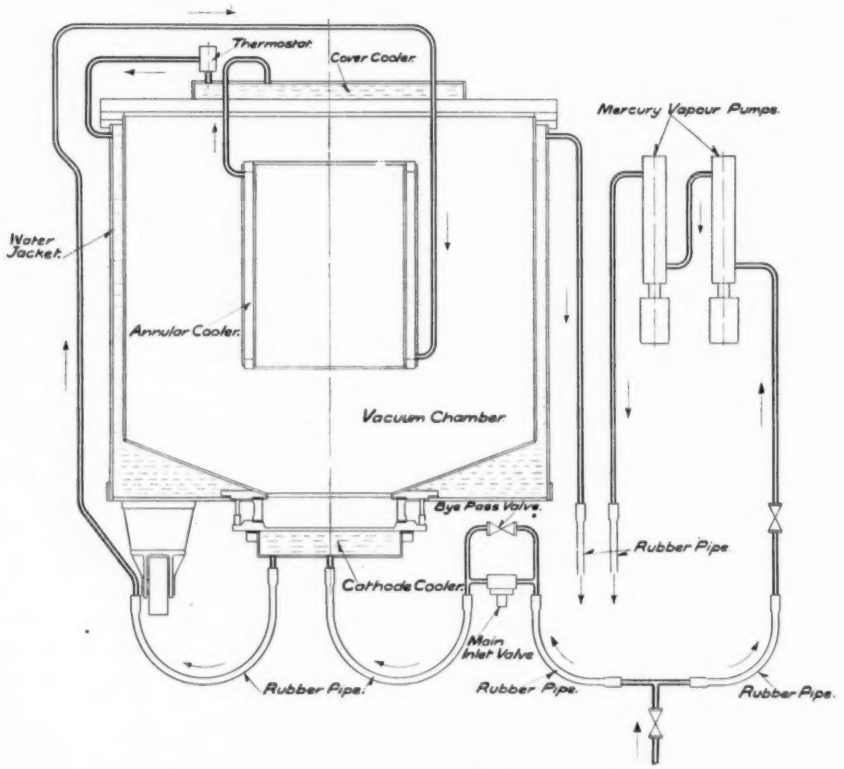


Fig. 6. Diagram of the Water Circulation System for Cooling.

A mercury-arc rectifier will not commence to operate merely by applying the working voltage to the anodes ; that is to say, an arc has first to be " struck " by an auxiliary anode, called the " ignition " anode. Similarly, the arc cannot be maintained with less than a certain absorption of energy in the cathode spot, and therefore the continuous operation of the rectifier on variable load necessitates the provision of an excitation arc that will persist so long as the rectifier is connected to the mains. The system of ignition and excitation (Fig. 7) developed for the " English Electric " rectifier is simple and reliable, both operations being performed by one auxiliary anode, that is supplied with direct-current at low voltage from a small rectifier of the glass-bulb type ; in some cases this may be replaced by a metal rectifier of the copper oxide type. The heating coil of the mercury vapour pump is connected in series with the excitation arc so that the auxiliary rectifier is able to operate at a voltage compatible with efficient working. This refinement constitutes a saving of some $\frac{3}{4}$ kW., and thereby reduces the no-load losses of the equipment.

For " ignition " it is necessary to bring the auxiliary anode into contact with the mercury cathode and then to withdraw it. This is accomplished in an ingenious manner by suspending the anode from a tubular iron float that is normally buoyant in a small annular cup of mercury, which serves also to convey current to the anode ; the anode stem is of steel, and its upper portion is surrounded by a solenoid, which, on being excited, draws the anode down against the buoyancy of the float. Immediately

the carbon tip of the ignition anode touches the mercury cathode and a current passes, the circuit of the solenoid is broken and the anode returns to its normal position drawing out an arc which at once causes the main arc to strike. In its normal position the auxiliary anode produces an excitation arc that preserves continuity of operation under all conditions of load on the unit.

Although D.C. ignition and excitation has been adopted as the standard system for English Electric rectifiers, an A.C. system may be employed, if desired. The latter system, however, requires at least one extra vacuum seal on the rectifier ; moreover, to attain stability of the arc at or near zero load, which is such an important feature of D.C. excitation, polyphase excitation is necessary, and this entails a number of auxiliary anodes in addition to the ignition anode.

The auxiliary equipment of a rectifier unit includes both the rectifier auxiliaries proper, such as the vacuum pumping and measuring equipment, which are mounted on the rectifier, as well as the accessory gear required for cooling the rectifier, supplying the auxiliary excitation, preventing interference with telephone circuits and protecting the rectifier against abnormal operating conditions.

No matter how tight the vacuum seals, or how free the rectifier from air leakage, a gradual liberation of occluded gas from the inner surfaces of the vacuum tank is bound to take place during operation. These gases must be continuously removed from the vacuum chamber if the rectifier is to operate correctly.

The pumping system employed for this purpose by the English Electric Company comprises a three-stage mercury vapour condensation pump operating in conjunction with an oil-sealed rotary exhauster. The former gives the necessary high pumping capacity at low pressures, whilst the latter provides the preliminary vacuum required for the mercury pump to work against. A barometric seal between the two pumps protects the rectifier vacuum chamber from an influx of air and gases when the rotary vacuum pump is shut down. The general arrangement of the vacuum pumping system is shown diagrammatically in Fig. 8. The barometric seal is combined with an oil trap, the purpose of which is to prevent oil or oil froth from entering the former during shut down of the rotary pump. A vacuum cock is provided in the vacuum pipe from the rectifier, but normally this is kept open, and it is shut only in the event of overhaul of the mercury vapour pump or of the vacuum connections.

The standard vacuum indicating equipment fitted to English Electric rectifiers is the Pirani gauge, which is direct-reading and suitable for automatic plants. The principle upon which the Pirani system of vacuum measurement depends is that at very low pressures the heat conductivity of a gas increases with pressure, so that the temperature, and therefore the resistance, of an electrically heated metal filament situated in the gas will be a function of the gas pressure.

In practice the metal-filament vacuum detector (Fig. 9) forms one arm of a Wheatstone bridge, which is supplied with direct current through

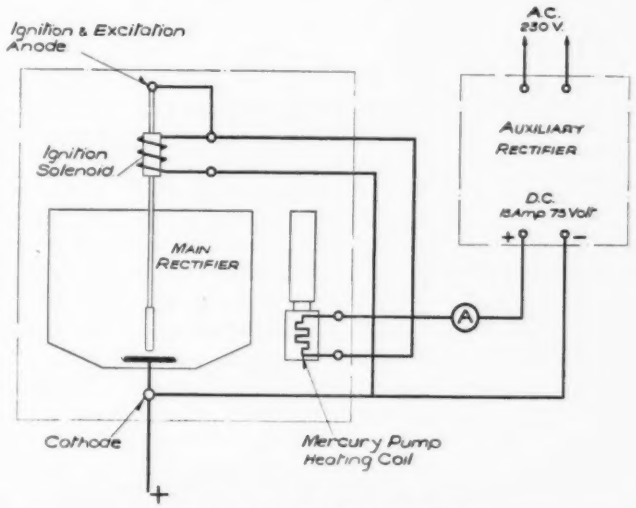


Fig. 7. Ignition and Excitation Circuits.

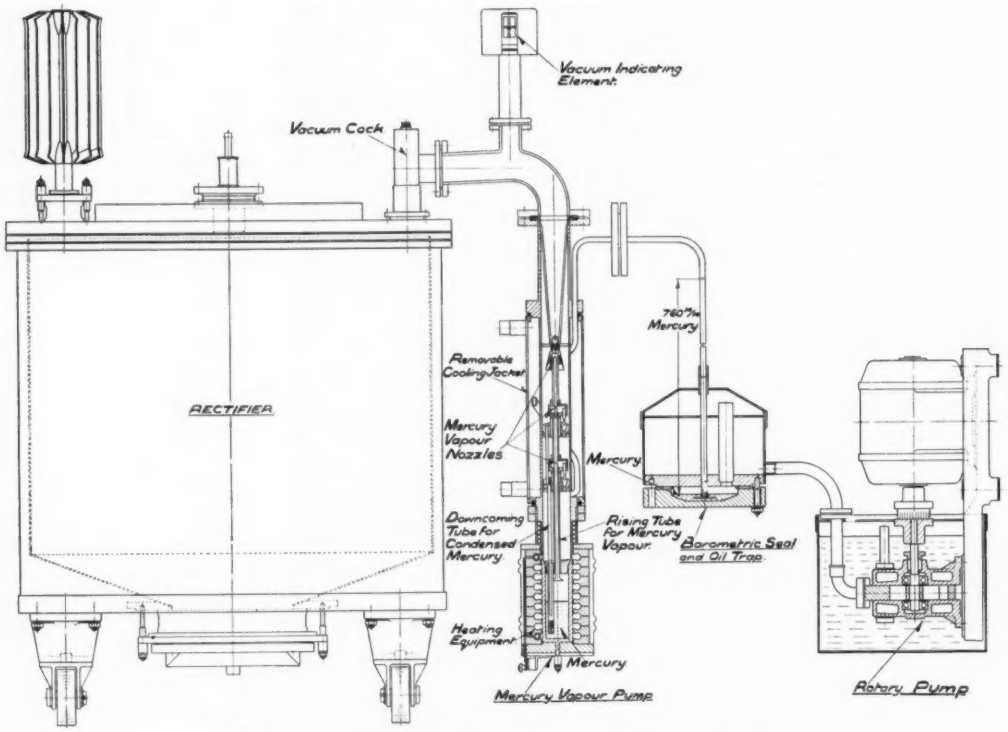


Fig. 8. General Arrangement of Vacuum Exhausting System.

a Barretter tube. The function of the latter is to make the bridge sensibly independent of voltage variations on the auxiliary D.C. supply. The resistances forming the remaining arms of the Wheatstone bridge, together with the vacuum detector, are combined into a vacuum transmitter that is connected to the vacuum pipe from the rectifier, between the mercury vapour pump and the vacuum cock. The resistance box, Barretter tube, regulating resistance and bridge voltmeter are arranged in a common housing, and may be conveniently mounted behind the switchboard. The vacuum indicating instrument is mounted on the rectifier control panel.

Where required, a McLeod compression gauge can be supplied and fitted as a check on the Pirani equipment. The McLeod gauge, however, although reliable, is a cumbersome piece of apparatus and has to be adjusted by hand every time a vacuum reading is required. For this reason it is unsuitable for automatic or remote-controlled rectifier installations.

The energy loss in the rectifier, manifested by the generation of heat, is dissipated by the cooling water which circulates through water jackets situated at the cathode and cover-plate, and surrounding the vacuum chamber. The internal cooling system of the vacuum chamber is also included in the cooling circuit as is shown in Fig. 6. A separate cooling water circuit is provided for the mercury vapour pump, as the latter is continuously in operation. The quantity of water required for cooling the rectifier depends upon the load, and is regulated by an automatic thermostat valve. In the English Electric rectifier a Samson regulator is employed, which gives close regulation, with economy in cooling water, and allows of accurate temperature adjustment.

Where water is scarce or costly, or where it is excessively hard or conducting, it is necessary

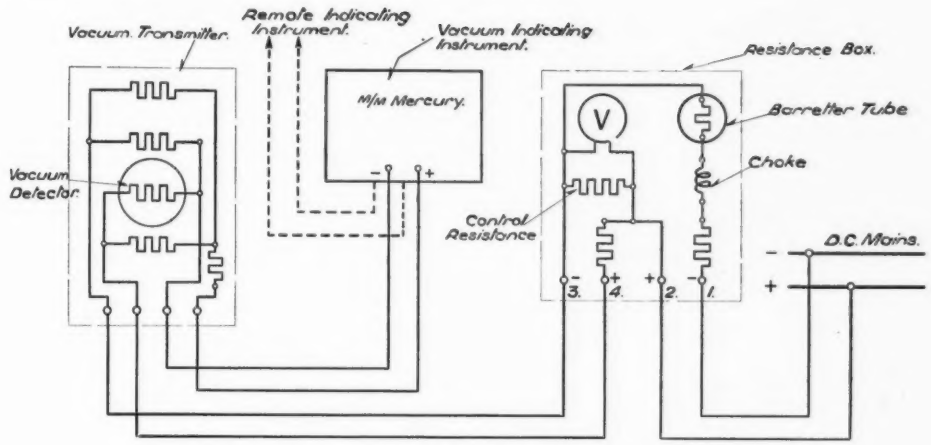


Fig. 9. Connections of Vacuum Measuring Apparatus.

to make use of a closed-circuit cooling system. Pure fresh water, or even distilled water, is then circulated through a re-cooler which may be of either the air-blast or the water-cooled type.

The D.C. voltage of a rectifier is not smooth, but is characterised by a ripple, due to harmonics of the A.C. supply frequency, which may possibly be a source of interference to neighbouring telephone circuits. Such interference is eliminated by a smoothing circuit consisting of a D.C. reactor in series with the load, together with several resonant shunts, tuned to the predominating harmonics, connected across the outgoing D.C. leads.

It is necessary to protect the windings of the main and interphase transformers from pressure surges generated by the mercury arc under certain conditions, viz., during a back-fire, and when a cold rectifier is thrown on a heavy load. Suitable surge protecting gear takes the form of low-voltage lightning arresters; English Electric rectifier units are adequately protected by auto-valve arrestors.

The rectifier is protected against overheating by a temperature relay situated on the inner side of the cooling water tank, and against failure of the cooling water supply by means of a contact manometer relay connected to the inlet pipe. A vacuum relay, operated from the Pirani gauge, further protects the rectifier from working under conditions of poor vacuum.

COMMERCIAL MOTOR TRANSPORT EXHIBITION
NOV 5 TO 14
1931
OLYMPIA

STAND No. 53.

Annexe.

A cordial invitation is extended to all our readers to visit our Stand at the

Commercial Motor Transport Exhibition at Olympia, November 5th to 14th.

A Double-deck, Six-wheel Trolley Bus with many novel features will be shown.

Summer Meeting of the Institution of Electrical Engineers.

Some Notable "English Electric" Contracts Visited.

The programme of visits arranged in connection with the 1931 *meeting, which was held in London this month and linked with the Faraday Centenary Celebrations, included no fewer than four installations for which the Company has been responsible. These represent thoroughly modern developments of applied electricity, of widely different characters, and afford striking testimony to the service which the Company is in a position to render in the advancement of transport, transmission, broadcasting and scientific manufacturing methods. Although descriptions have appeared in this Journal and elsewhere, the contracts are of sufficient interest to justify recapitulation, with the inclusion in some cases of references to later stages of the work.*

High-tension D.C. Generators and other Power Plant at the London Regional Broadcasting Station,

visited September 22nd, 1931.

The high-tension direct-current generating plant, illustrated below, comprises three motor-generator sets, each having a continuous rating of 160 kW. at 12,000 volts. Each set consists of a 725 r.p.m. direct-current motor driving two generators. Each armature of the two high-tension generators has a commutator at both ends, and the four commutators are connected in series. A four-pole construction has been used for these machines, as it has been found by experience that for any but the smallest sizes the abnormally long end windings on two-pole machines are difficult to insulate, and are, moreover, mechanically weak when wound with copper of the very small section required for machines of this output and voltage. The interpole and series windings are connected on the negative side of the armature, as shown in the diagram of connections on the next page.

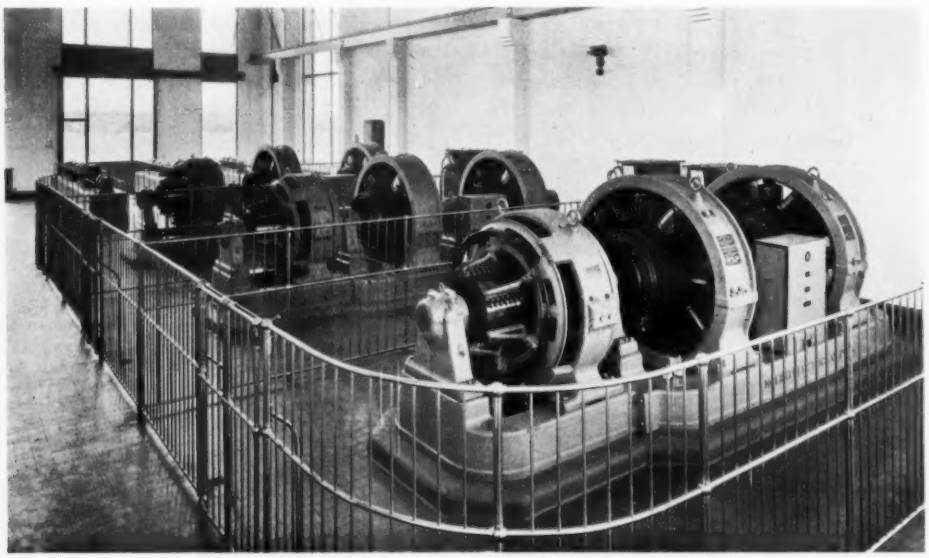


Fig. 1. Three 12,000-volt, 160 kW., Direct-Current Generators.

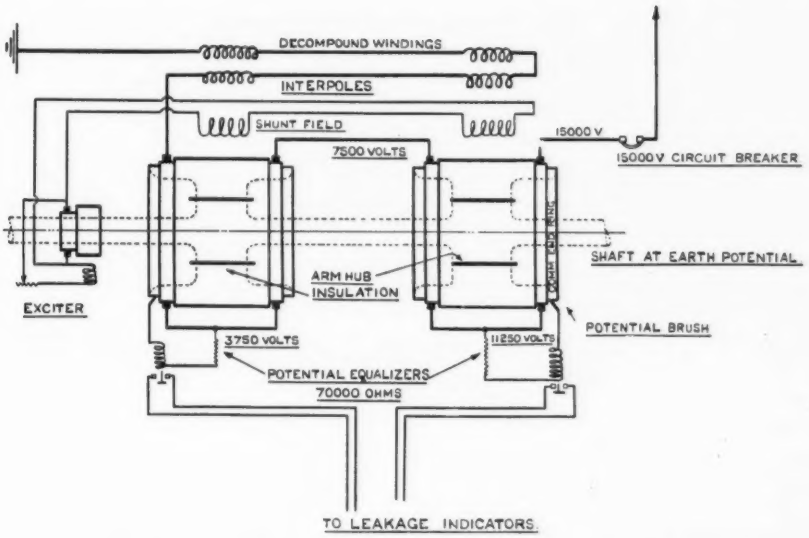


Fig. 2. Connections and Insulation Diagram of a High-Tension D.C. Generator.

The voltage per commutator is 3,000, and this is the total dielectric stress on the slot insulation.

The major insulation to ground is incorporated in the armature hub, where it takes the form of a layer of pressed mica with liberal creeping distances. This insulation is capable of withstanding 20,000 volts for a long period, and was tested with a 50-cycle alternating pressure of this value for one minute.

A potential equaliser and trip gear is provided for each generator of a pair, to ensure that the potential of each armature core is maintained midway between the potentials of the two commutators; the dielectric stress between the slot insulation and the armature hub insulation is thus distributed in a definite and constant manner.

The limiting resistance in the potential equaliser circuit has a value of 70,000 ohms, and is connected to the armature hub by means of a light brush, running on an extension of one of the commutator end-rings. If any current flows in this resistance due to leakage caused by some insulation defect, a relay comes into operation and gives warning by means of a lamp or bell.

One insulation fault in either the slot insulation or the hub insulation does not necessarily prove serious, as all insulations are capable of withstanding any increase of potential that may arise under fault conditions. Therefore, there is always ample time for another set to be brought into service.

The insulation scheme outlined provides double security and gives sure warning of any insulation trouble. The potential equaliser and leakage trip gear consume no energy, and require no attention. They can be relied on to operate after very long periods of inactivity, as provision is made for tripping and resetting the gear at any time, even when the machine is in service.

Limitation of the current that can flow in the event of a short circuit is effected by heavy decompounding windings in conjunction with a series choke coil for each set. The latter reduces the rate of increase of current on short circuit to such a value that the current rush can be checked by the reverse series winding.

Excitation is provided from the 220-volt station mains, and the whole of these circuits are at or near earth potential. The main generators are perfectly stable over a wide range of voltage variation.

The frames of the machines operate at earth potential, but the insulating scheme provides for the negative terminal and all windings on the negative side to withstand a pressure test of 5,000 volts, and hence the actual earth connection can be made at a point remote from the machine.

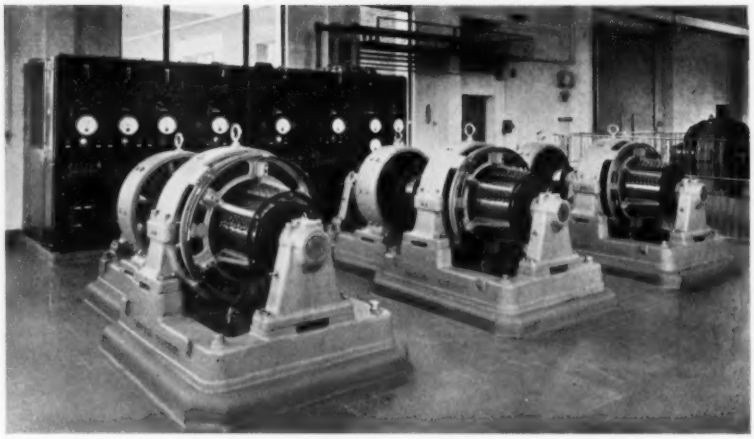


Fig. 3. Filament-current Motor Generators and Control Board.

The motor-generator sets are completely enclosed by an earthed steel railing, the entrance gates in which are interlocked with the main switchgear in such a way that they must be closed and locked before the plant can be started up.

The main power supply is derived from four 200 kW. shunt-wound generators driven by oil engines. These machines run at 300 r.p.m., and give their output at any pressure from 200 to 260 volts.

For supplying the filament current there are three motor-generator sets (Fig. 3), each of which gives 1,300 amperes at any pressure between 15 and 30 volts. For battery charging purposes two reversible booster sets are provided, each having a one-hour rating of 400 amps. at 70 volts, or 1,000 amps. at 35 volts.

Control of the output sides of the high-tension sets and filament-current sets is effected from a 25-panel switchboard in the Transmitter Hall. The illustration of this board, reproduced in Fig. 4, shows the main circuit breakers for the high-tension sets at the top of the centre panels. Three other main switchboards control the generators in the Engine Room, the supply to the filament current sets, and various auxiliaries.

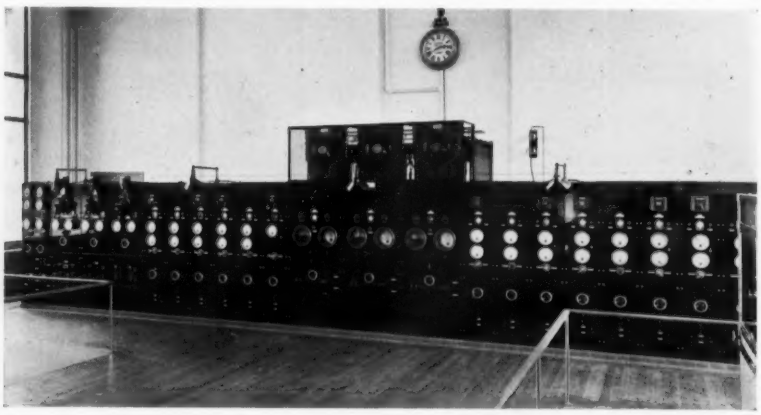


Fig. 4. Switchboard in Transmitter Hall for High-Tension and Filament-Current Generators, etc.

Automatic Electric Railway of the Post Office, London,

visited September 22nd, 1931.

As shown in the plan, Fig. 5, this line runs east and west for a total length of about 6½ miles, and connects eight important main-line railway

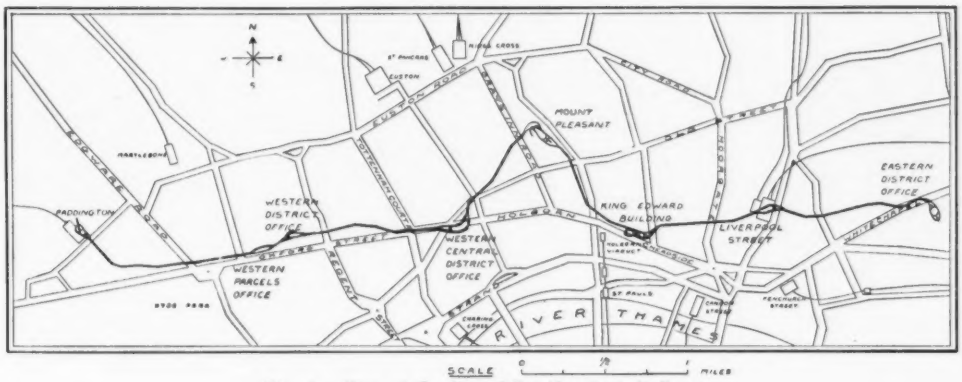


Fig. 5. Plan of the Post Office (London) Railway.

stations and mail depots. The gauge is 2 ft., and direct-current power is supplied to the trains from a third rail at 440 volts, except for station and siding sections, to which a supply is given at 150 volts. The free running speed and maximum speed are approximately 30 m.p.h. and 40 m.p.h. respectively.

Between stations the operation is entirely automatic, but in the station sections it is controlled, with automatic safeguards, from the station operator's control desk ; a Route Lever system is employed, and all the points are motor-driven. The third rail is divided into insulated sections, and automatic safety control is obtained by continuous track-circuiting operated from a 24-volt direct-current supply.

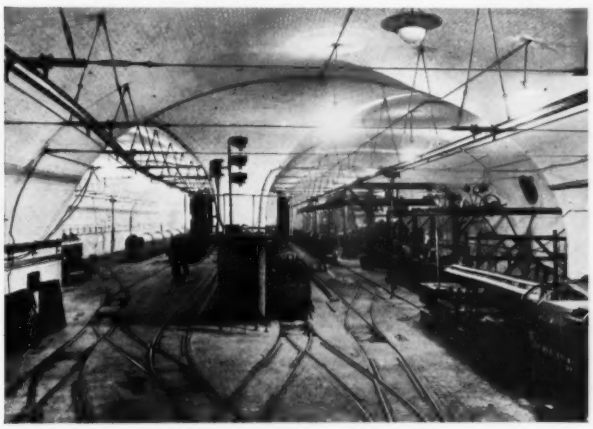


Fig. 6. General View of Car Depot.

To ensure accurate stopping of the trains at the platforms, while maintaining a high average speed between stations and the maximum possible acceleration and deceleration, a braking or dead section is provided, on which the train first comes to rest momentarily, under the action of its automatic brakes, and then starts again automatically, at first on 440 volts, and then on the 150-volt supply, until a dead platform section is reached. These operations are effected automatically by a camshaft controller, the train fulfilling the function of a master controller, and the cam-operating motor that of a time controller.

Shunting into and out of sidings is automatic, the only part that is done by hand being the reversing of the train ; otherwise the working is performed by a camshaft controller.

The various contactors, relay cabinets, batteries for the track circuits, motor generators, etc., are housed in the switchroom or substation underneath the island platforms.

The rolling stock originally used consisted of ninety four-wheeled wagons made up into three-wagon trains. Fifty vehicles of a larger and improved type that have now been put into service, differ from the earlier ones mainly in their mechanical design ; they have a tare weight of 4.1 tons, of which 81 per cent. is on the driving axles, a carrying capacity of 1.8 tons, and an overall length of 27 ft. 6¼ in. These wagons, an exam-

ple of which is shown in Fig. 8, operate either singly or coupled in pairs, and consist of a self-contained power unit on a maximum-traction bogie at each end, with a connecting floor supported on special seatings. The bogies have 2 ft. driving and 1 ft. pony wheels, with a wheelbase of 4 ft. ; each carries a 22 h.p. motor, resistances, reverser, brake release solenoid, brake application springs, and current collector gear. The brake solenoid is permanently in series with the motor and holds the brakes "off" so long as power is being taken ; powerful springs apply the brakes whenever the train runs on to a dead section or power is switched off. A hand-wheel, that is interlocked with the reverser, permits the brakes to be screwed off in case of emergency.

Fig. 7. An Operator's Cabin and Control Desk.

Each wagon accommodates four standard containers for the loading and unloading of which a hinged ramp is lowered on to the platform ; simple security devices are fitted to all movable portions.

In the car depot and workshops current is collected from a double overhead wire by trolleys running on suspended guides and connected to the wagons by flexible cable ; all movements are controlled from an elevated platform. For general service and emergency work three 50 h.p. battery locomotives are available.

INTERESTING STATISTICS.

150,000 tons of mails are carried per annum.

12¼ million car miles have been run.

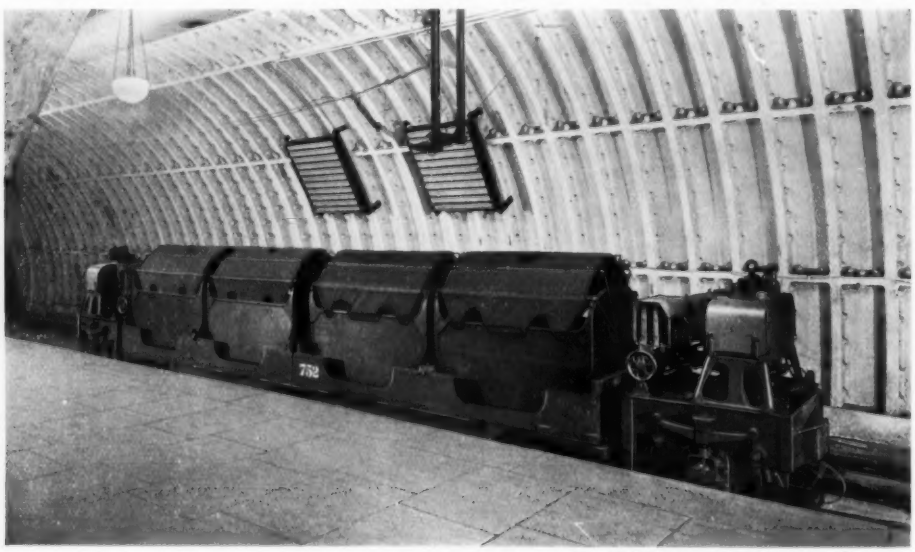


Fig. 8. Maximum-Traction Bogie Wagon in Service.

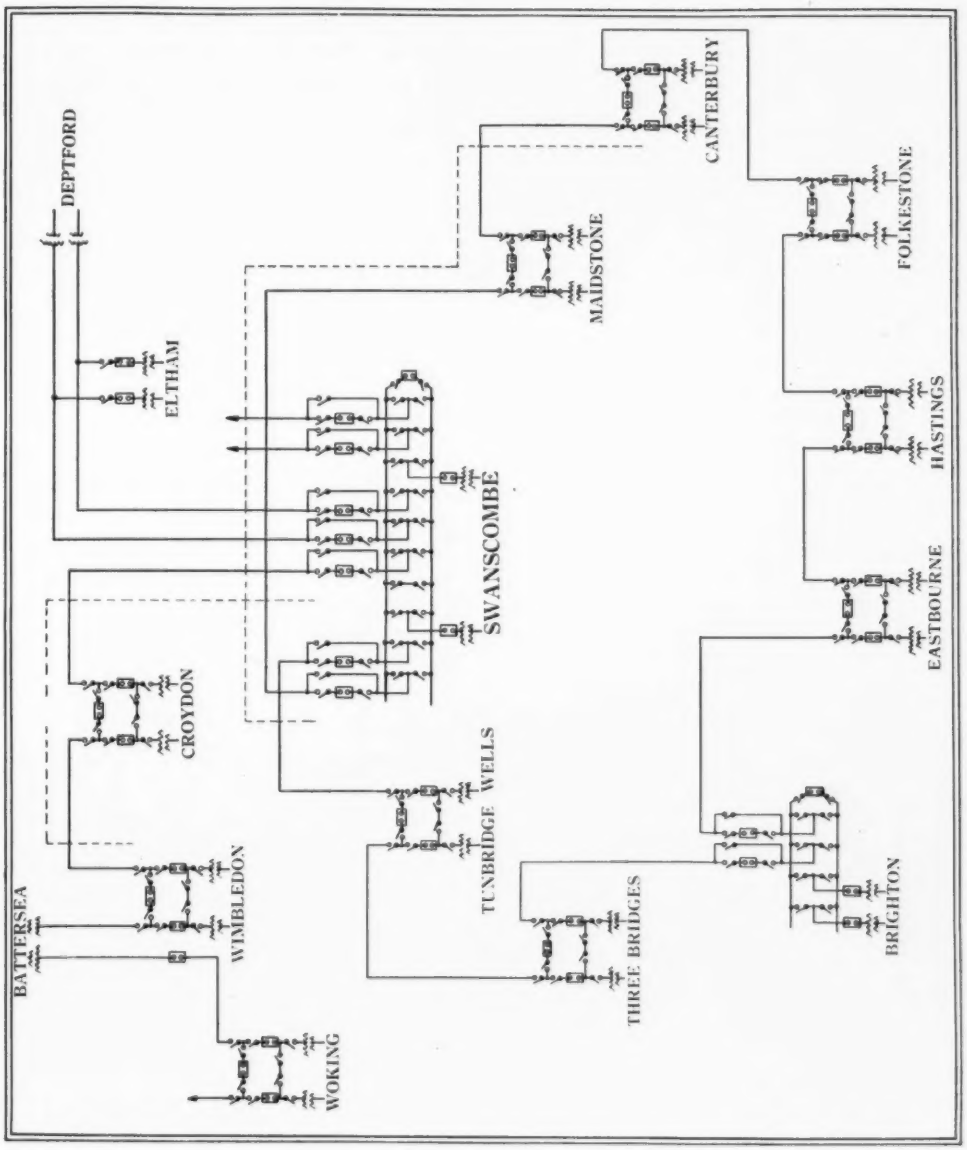


Fig. 9. Diagram of 132 kV. switching stations in the Southern Section of the S.E. England Scheme.

Mail is carried for 132 hours per week, i.e., the line load factor is 78 per cent.

Headway at rush hours, two minutes.

45 miles of power cabling, and 77 miles of signal and control cabling were used.

There are 1,047 relays making 6,351 double contacts.

Capacity of substation plant 2,400 kW.

132,000-volt Switching Station of the Central Electricity Board at Swanscombe,

visited September 24th, 1931.

The South-East England Scheme of the Central Electricity Board comprises an area of nearly 9,000 square miles, in which the total demand is the largest of any of the ten regional districts. It can be divided into a northern and southern section, on each of which there are thirteen main switching stations for the primary 132 kV. transmission. Fig. 9 is a diagram of the thirteen southern stations that are being equipped by the English Electric Company. In addition to these 132 kV. stations the Company has been entrusted with many lower-voltage switching equipments for linking power stations to the "Grid," and some of these are illustrated and referred to later. The switching stations of the southern area shown on Fig. 9 are all interconnected on the 132 kV. system with the exception of Woking, and are linked with stations in the northern area of the scheme by the lines from Swanscombe to Barking and from Woking to Uxbridge.

It will be seen also from Fig. 9 that many stations are of the three-switch type, an arrangement that has been fully described elsewhere, and as an example a view of Hastings is shown in Fig. 11. This type lends itself admirably to a simple and orderly layout of the gear, the advantages of which can be extended to comparatively large centres, such as that at Brighton, a view of which is reproduced in Fig. 13. At this station there are five 132 kV. circuits equipped with oil circuit-breakers, while bye-pass switches are provided on the feeders to Three Bridges and Eastbourne.

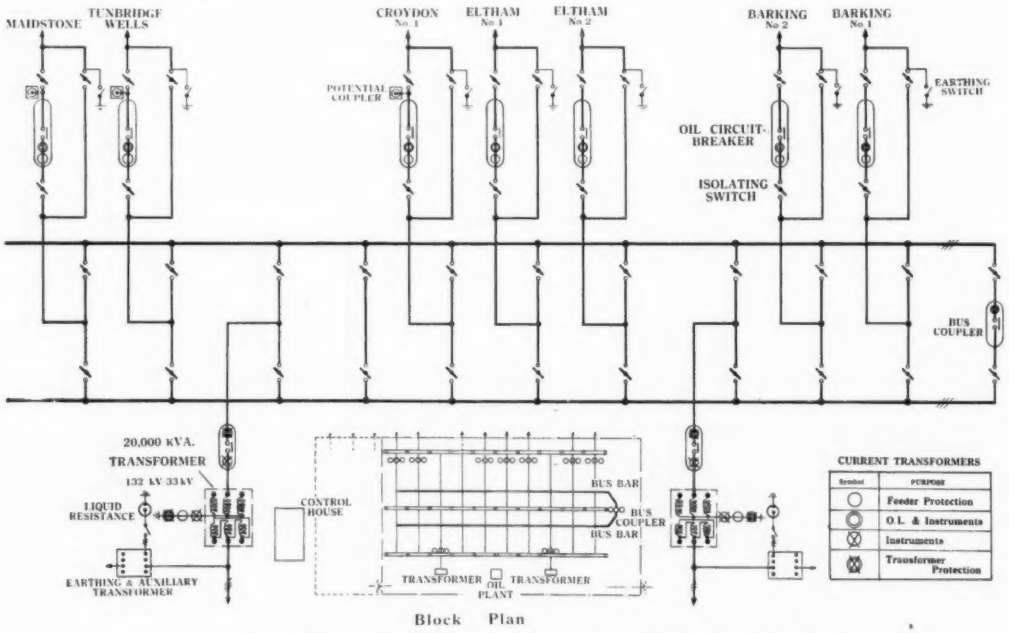


Fig. 10. Single-line diagram and Block Plan of Swanscombe Switching Station.

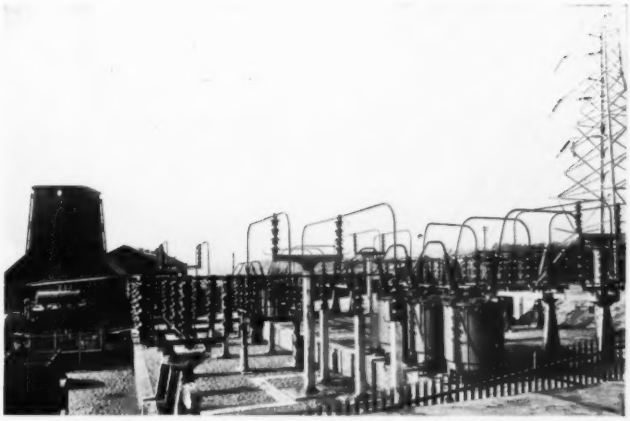


Fig. 11. Hastings 132 kV. Switching Station.—Three-switch type.

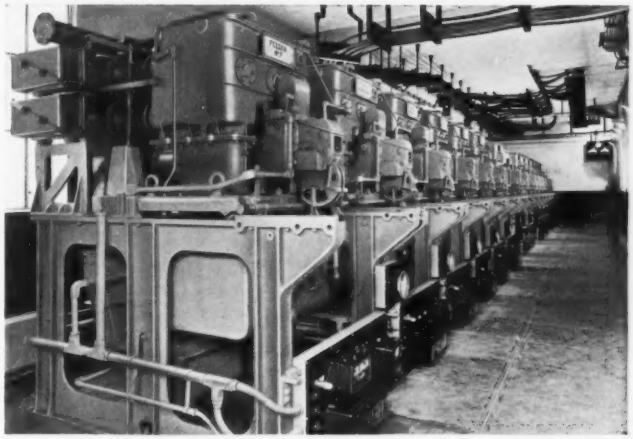


Fig. 12. New 11,000-volt Metal-clad Switchboard at Hastings linking the Corporation system to the "Grid."

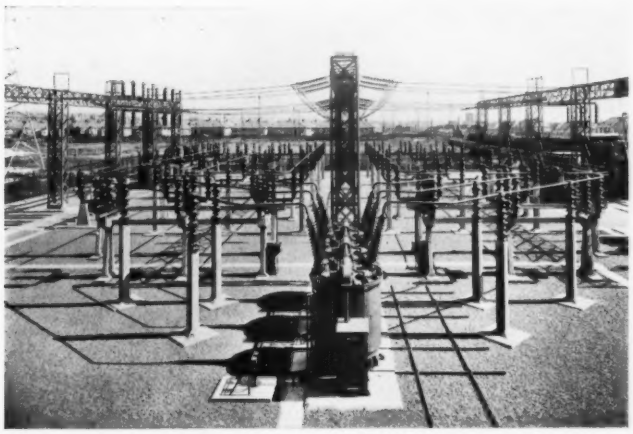
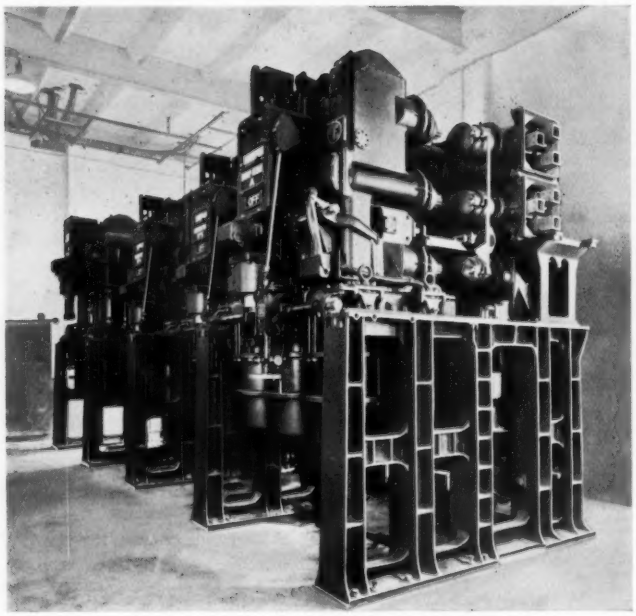


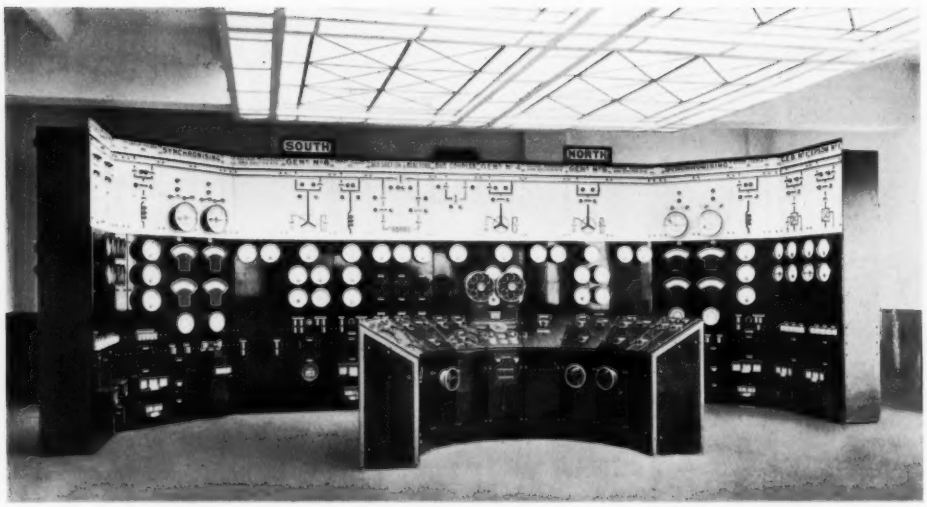
Fig. 13. 132 kV. Switching Station at Brighton.



Figs. 14 & 15.

1,000,000 kVA. Metalclad Switchgear at Croydon.

Four of the seventeen units in course of erection, and (below) the Control Board and Operating Desk.



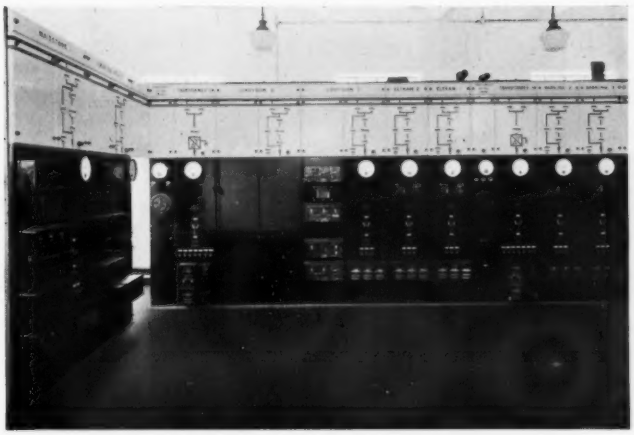


Fig. 16. 132 kV. Control Board at Swanscombe.

Swanscombe 132 kV. switching station, which is the main subject of this note, is the largest 132 kV. switching station of the "Grid," and is the switching centre linking the London area with the systems in Kent and Sussex. It is of the Board's "Low Double-Busbar" type, with equipment for controlling seven circuits, and two 132/33 kV. transformers, each of 20,000 kVA.; ample provision has been made for future extension. Fig. 10 is a diagram of connections, and a block plan of the station, while general views of the station and of one of the switching "avenues" are shown in the frontispiece.

There are ten 132 kV. oil-breaker banks, one for each line and each transformer, and a bus-coupler. The breakers have a separate tank for each phase, and have a rated current-carrying capacity of 600 amps., and rupturing capacity of 1½ million kVA. Each single-phase unit has four breaks in series with two main contacts. The tanks are of mild steel ½ in. thick, with a diameter of 6 ft. 6 in., a height of 7 ft. 3 in., and an oil capacity of 1,350 gallons; rails are provided to facilitate removal of any unit, and permanent piping connects each tank to the central oil purifying plant. Bushings of the oil-filled condenser type are mounted in the steel top-plate, and bushing type current transformers are enclosed within the mounting.

The breakers are actuated by solenoid mechanism contained in a steel cupboard situated at the end of the bank, and switching is carried out from a control house at one end of the site.

The 132 kV. isolating switches are of the rotating centre-pivot type mounted on massive tubular frames. The three units for one circuit are coupled mechanically, and operated by hand-lever from ground level through an operating box which contains an electromagnetic bolt actuated from the drop-down handle, and interlocked with the associated oil breakers. The special type of contact is designed to eliminate difficulty in operating the switches in severe winter weather.

Copper tube 3 in. in diameter is used for the main busbars and, like the busbar insulators, these are supported on four-unit post isolators carried on concrete pillars. All the auxiliary cabling for electrical operation, interlocking, lighting, etc., is run in trenches covered by concrete slabs, and the oil piping is installed in a similar manner.

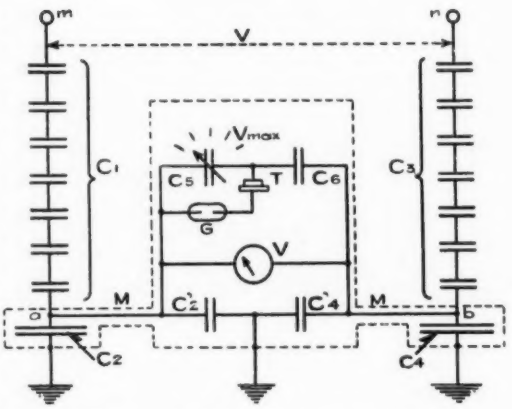
Protection of the transformers is by means of overload and restricted earth-leakage relays, and that of the feeders is on the split-pilot or ratio-balance system, according to the length of the line.

Control of the whole substation is centred in a brick building, which houses also the switchgear for the 33 kV. circuits. The 132 kV. control board is of the steel cubicle type, the front being formed by the slate panels that carry the control switches and mimic diagram, while access at the back is obtained through steel doors; the opening of the latter causes the lighting to be switched on in the particular cubicle. The semaphores in the diagram are actuated electrically from the particular pieces of apparatus which they represent. In the same room are installed the control board for the 33 kV. switchgear and a low-tension auxiliary switchboard for controlling the supply from a 110-volt battery to the oil-breaker solenoids and some emergency lighting.

Some reference to the lower-voltage equipments may be of interest, since at many of the 132 kV. switching stations they are installed either in the

control house, as at Swanscombe and Three Bridges, or in a power station adjoining the site, as at Hastings, Tunbridge Wells and Croydon. One of the most important of these equipments is that which is now being erected at Croydon ; it comprises seventeen metal-clad units having a rupturing capacity of one million kVA. at 6,600 volts, and a current-carrying capacity of up to 3,000 amperes. Some of the units, which are amongst the largest yet built, are illustrated in Figs. 14 and 15. The boards are of the duplicate busbar type, and the " box " type bars have been designed throughout to carry 4,000 amperes continuously. Changeover from one set of bars to the other is made by oil-immersed selector switches arranged for operation under load. With the exception of the selectors, which are operated manually, the whole of the switching is effected electrically from a control room.

The control board at Croydon is of the upright cubicle type forming three sides of a rectangle, and in the front of it is a semi-circular desk board from which are controlled the main power station generators, the feeders of the Central Electricity Board, signalling, telephones, etc. This arrangement is frequently adopted on installations of large size and gives complete control of all main circuits from one point. Fig. 12 illustrates the lower-voltage switchgear in the Broomsgrove



G = Neon Tube. T = Telephone. M = Earthed Screen.

Fig. 17. Voltmeter Connections.

Power Station, Hastings ; although these metal-clad units have a rupturing capacity of half-a-million kVA., they are operated by hand, a simple design of mechanism having been evolved which gives the speed of closing necessary for synchronising operations without difficulty, in spite of the large size of the units.

High-voltage Testing Laboratory of the Woolwich Works of Messrs. Siemens Brothers & Co., Ltd.

Fig. 18. General View of High-Tension Testing Equipment.

This equipment was installed mainly for testing single-core cables for working at pressures up to 76 kV. to ground, that is to say, on 132 kV. three-phase systems, and three-core cables operating at 66 kV. between cores. It is designed for a wide variety of tests, including measurements up to 100 kV., and breakdown, flashover, and other tests up to 450 kV.

Since accurate measurement of small losses at very low power factors requires a voltage wave form free from harmonics, the power

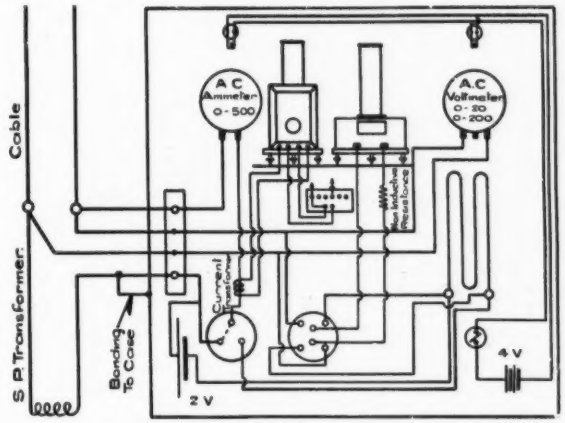


Fig. 19. Diagram of "Resistance Measuring Cupboard" for Cable Loading.

supply plant was designed as an integral part of the equipment.

The illustration opposite gives a general view of the testing area from the control gallery. It includes three enclosures surrounded by expanded metal screens 7 ft. high, with a single entrance to each enclosure, which is interlocked with the main switchgear.

Power is furnished by a 525 kVA., 550-volt single-phase alternator, driven by a three-speed A.C. motor, so that the frequency may be 50, 37.5, or 25 cycles per second. From tests made at these frequencies the performance of a cable at any commercial frequency can be deduced. The alternator is designed to give a good wave form, and special precautions were taken to suppress the principal harmonics produced by the testing transformers. Any risk of instability is eliminated by the use of an auto-connected induction regulator for varying the voltage applied to the testing transformers. The pressure may be regulated in this way from 0—1,100 volts. Oscillograph films taken on a capacity load show that a practically pure sine wave is obtained under working conditions.

Pressure measurements may be made by a horizontal sphere gap having 500 mm. duralumin spheres, or, when greater accuracy is required, by direct-reading instruments. The latter include a potential divider, and a Neon tube for measuring the crest voltage. The arrangement is shown in the diagram of Fig 17.

Wave form can be observed and recorded on an oscillograph, suitable for use up to the limit of the measuring instruments, i.e., 100 kV.

High-voltage tests can be applied to cables carrying current corresponding to their working or other load. The cable current is led through a Resistance Measuring Cupboard, arranged as shown in Fig 19.

The measurement of dielectric losses is an important item in testing cables for very high voltages. Two methods are available (1) Duddell-Mather wattmeter, and (2) Schering Bridge. The difficulties of making accurate loss measurements with a wattmeter at very low power factors are well known. A special design of resistance is employed in this equipment, in which there is no other metal than the resistance wire and the terminals. There are four resistance tanks, each containing a .25 megohm, oil-immersed resistance. Accurate loss measurements are made on the Schering Bridge.

The "pure" loss free condenser used in this bridge was the subject of very careful design and manufacture. It has a capacity of .0001 micro-

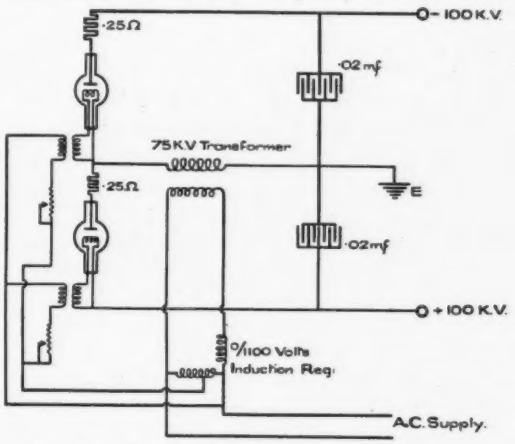


Fig. 20. 200 kV. Direct-Current Testing Equipment.

farad, and weighs approximately 1¾ tons. The bridge was designed to give an accuracy to within .00001 radian phase angle, which is 0.25 per cent. on a dielectric of .004 power factor.

High-voltage direct-current testing of cables enables much valuable information to be gained from the resulting electrification curves. An equipment for obtaining 200,000 volts D.C. is included in the testing plant. This consists of a 5 kVA. induction regulator giving 550/0 to 1,100 volts, and feeding a 75 kV. transformer. A diagram of connections is given in Fig. 20.

1,500-volt D.C. Electrification of the Madras Suburban Section, South Indian Railway.

Fig. 1. Motor Coach Trains in sidings at Tambaram Depot.

The first suburban railway electrification in India was that of the Bombay lines inaugurated in 1925, for which, it will be remembered, the English Electric Company supplied the whole of the train equipments for operation on a 1,500-volt d.c., overhead-line system. The initial electrification scheme in the southern part of the continent, which is the subject of this article, and which has been carried out on the same system, is of special interest in that it was not merely the conversion of existing steam-operated lines to electric working, but included the construction of new tracks and stations to accommodate suburban traffic that had increased so much as to impede the main-line services.

A new double-track for the electric trains has been constructed from Madras to Tambaram, a distance of 18½ miles, and certain shunting yards in the neighbourhood of the former have been electrified so that shunting operations and freight services can be carried out with electric locomotives. A contract was placed with the company in 1929 for the whole of the rolling stock required, and this has been constructed to the specification, and under the supervision, of the Railway Company's consulting engineers, Messrs. Robert White and Partners. This material was delivered early in 1930 and, after preliminary tests had been carried out, the new lines were opened on April 2nd of this year by His Excellency, the Governor of Madras: the public services were commenced in the

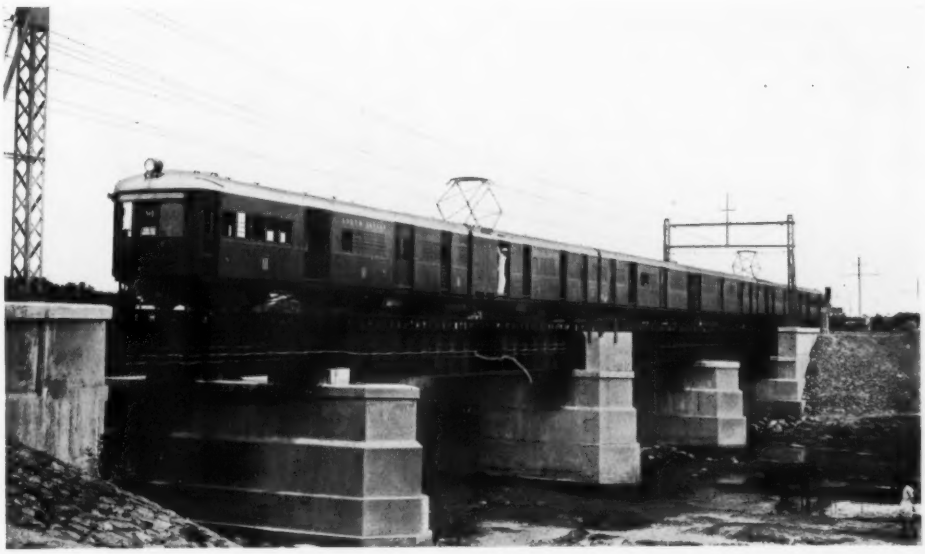


Fig. 2. 6-coach Train crossing Cooum River at Chetput.

Fig. 3. Train in Service near Pallavaram.

following month. A sketch map of the new line is reproduced in Fig. 5.

The order comprised 17 three-coach articulated units, each consisting of one motor coach and two trailer coaches, and four locomotives with two battery tenders.

The articulated motor-coach units are arranged for multiple-unit working so that trains may be made up with three, six or nine coaches, according to traffic requirements. The electrical equipment has been designed to give an average speed with a fully-loaded train of 40 miles per hour over the whole distance, with station stops at an average interval of 1½ miles.

A three-coach unit is carried on four bogies, and the power equipment consists of four DK 90 motors of 122 h.p. each, connected permanently in pairs in series, one pair being mounted on each of the two intermediate bogies. The motors are of the self-ventilated type, but owing to the excessively dusty conditions the ventilating air is drawn from inside the coach through ducts and sliding flexible joints.

Control is on the Company's all-electric camshaft system, similar to that in use on the Great Indian Pensinsula Railway, the Capetown Sub-urban system, and many other lines. The whole of the control equipment is housed in a compartment at one end of the centre coach, and this contains also a 4-kW, 1,500/60-volt motor-generator set for supplying the control and lighting circuits, and an exhauster driven by a 1,500-volt motor. All air entering the compartment passes through filters contained in the walls. In order to facilitate maintenance work, the main and auxiliary control apparatus is mounted on two self-contained removable frameworks. The control circuits are supplied from the motor-generator set at 60 volts, and an emergency battery, which is charged automatically, floats across the terminals of the set.

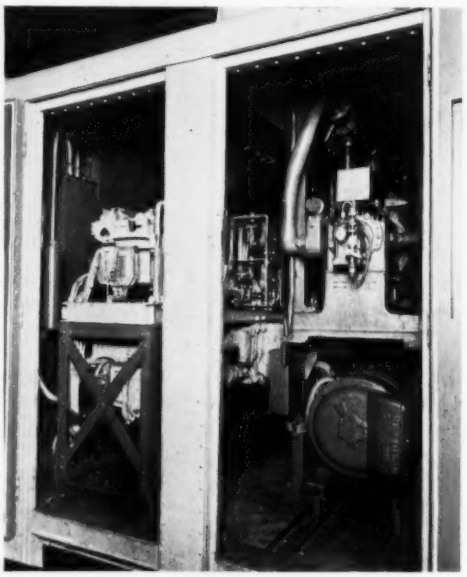


Fig. 4. Control Compartment of a Three-coach unit.

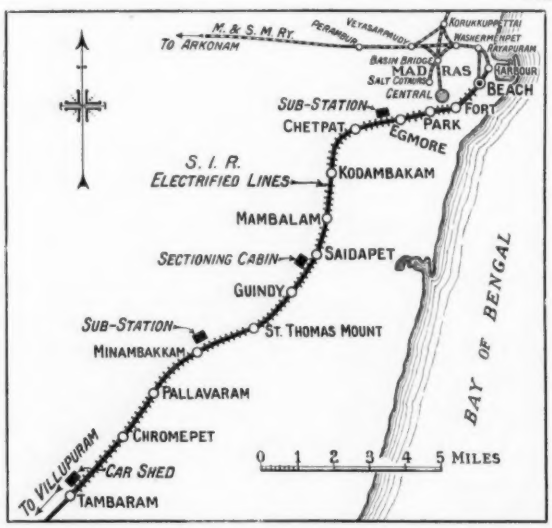


Fig. 5. Sketch Map of Madras Electrified Lines.
(By Courtesy of The Railway Engineer.)

The whole of the equipment was fitted into position at the Company's Preston works, and the first 3-coach unit was run on the test track before dispatch. Of the seventeen units supplied, ten were composite first, second, and third class, arranged to suit the local customs, and the remaining seven were third-class units; the seating

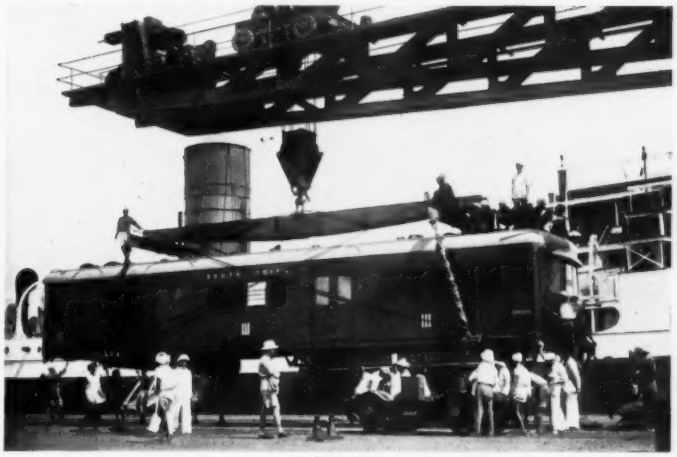


Fig. 6. Unloading a Motor-Coach.

Fig. 7. Electric Locomotive with battery tender in shunting service at Egmore Yard, Madras.

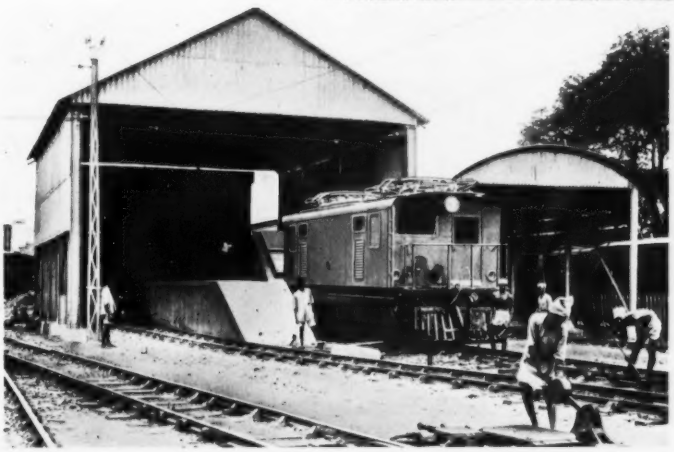


Fig. 8. Locomotive and battery tender in the charging shed at Egmore Yard.

capacity of the latter is 194. The total weight of a unit is 73 tons, or less than half a ton per foot run of the overall length of 150 feet.

In addition to the multiple-unit stock just described, the contract included the supply of four electric locomotives of the 0-4-4-0 type, having articulated bogies, each equipped with two nose-suspended axle-hung DK-128 motors, rated at 160 h.p. As in the case of the motor-coaches the ventilating air is drawn from the interior of the vehicle, which in turn has air inlets fitted with filters. The superstructure is of the box-cab type, with the control equipment mounted in a centre compartment, and a driving position at each end.

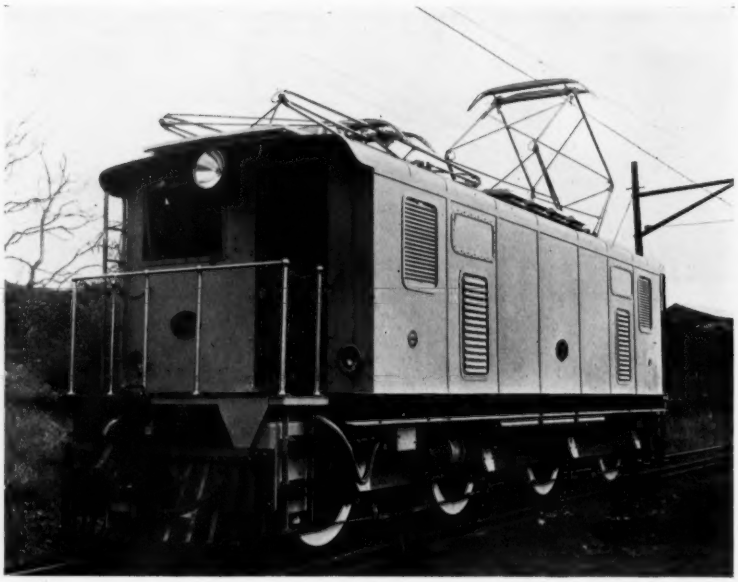


Fig. 8. One of the Locomotives on the Test Track at Preston Works.

The electrical equipment of the locomotives is generally similar to that of the motor-coaches, with the exception that it is not arranged for multiple-unit operation, and that three running positions are provided in series, and also in parallel by means of weakened-field notches. The locomotives are capable of hauling 500-ton freight trains, or 250-ton passenger trains, at speeds of from 25 to 40 miles per hour; they they have a length over buffer beams of 32 feet, a width of 8 feet 6 inches, and a weight of 42 tons; braking of the units themselves is by compressed air, but vacuum brake gear is fitted in addition to suit the existing rolling stock.

One of the chief difficulties encountered in laying out this electrification was the fact that there were a number of small yards at some distance from the main line which could not conveniently be provided with overhead construction, although, at the same time, it was extremely undesirable to have to provide a steam locomotive whenever movements had to be carried out at these yards. The problem was solved by providing, in addition to the locomotives, two battery-tenders equipped with heavy-duty batteries, capable of supplying the locomotives at 440 volts. When a locomotive is required for service of the kind indicated, one of these tenders is attached to it, and after the limit of the overhead construction has been reached, the pantograph is lowered, and by changing over a single switch, the locomotive runs on the 440-volt supply from the battery. These tenders, which weigh only 21 tons, have a capacity of 158 kW-hours at the five-hour rate of discharge of the battery. A complete charging switchboard and an auxiliary air-brake compressor, operating at the lower voltage, are carried on the tender.

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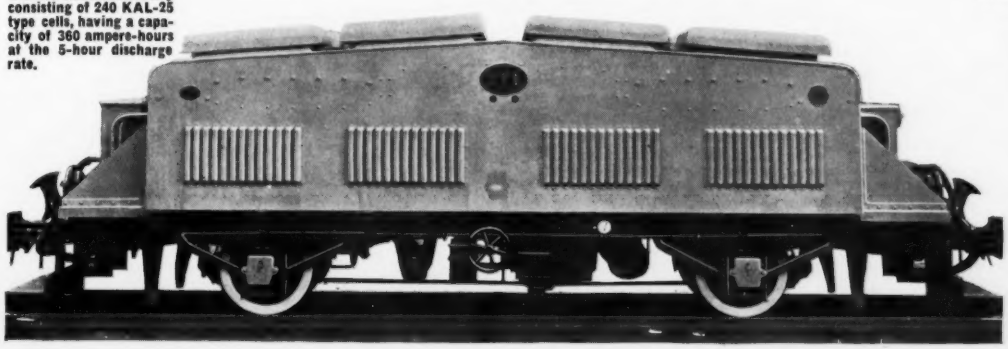
One of the battery tenders. Each tender is equipped with a Kathanode Battery consisting of 240 KAL-25 type cells, having a capacity of 360 ampere-hours at the 5-hour discharge rate.



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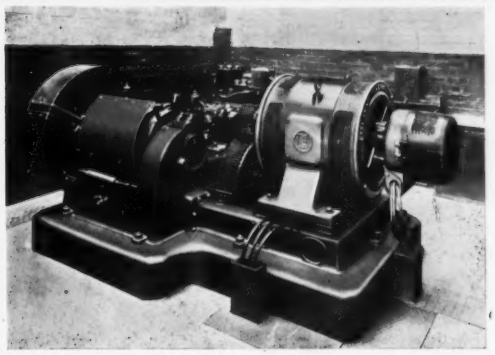

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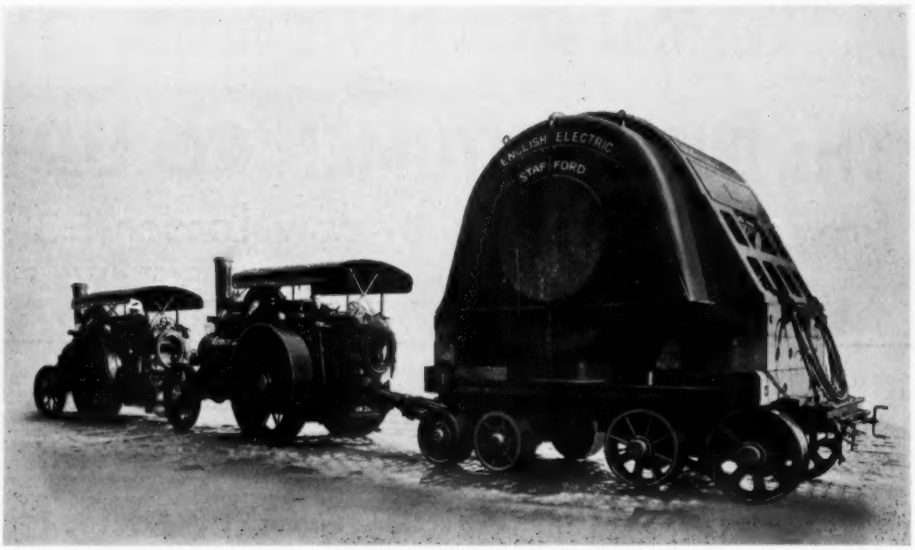

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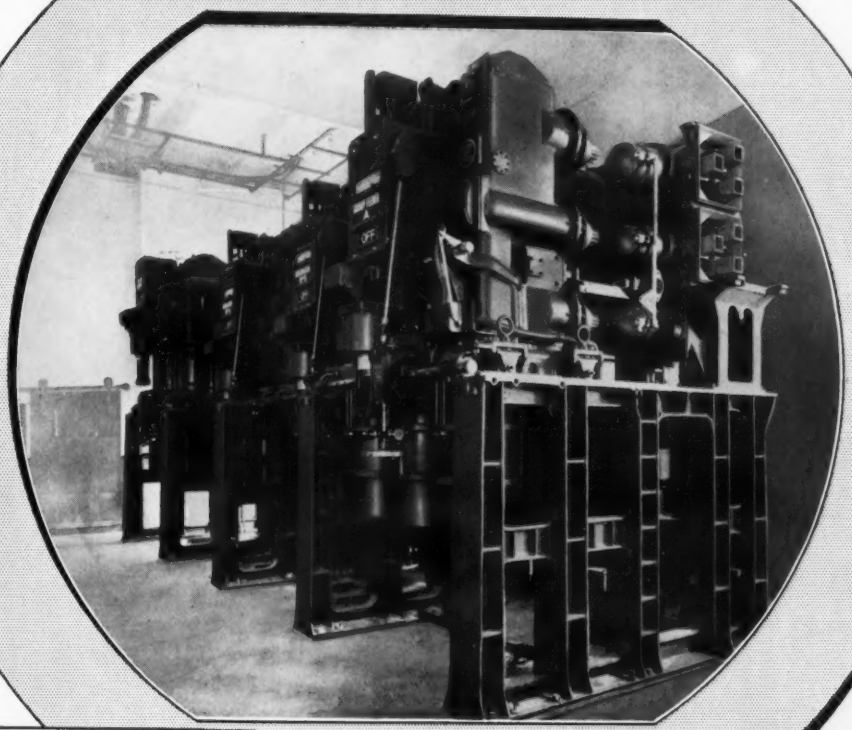

Sixteen of these Metalclad Units, amongst the largest yet built, were supplied by the English Electric Co., Ltd., to the Croydon Corporation. Each Circuit Breaker has a rupturing capacity of 1,000,000 kVA, the current rating being 3,000 amperes, and the working pressure 6,600 volts.

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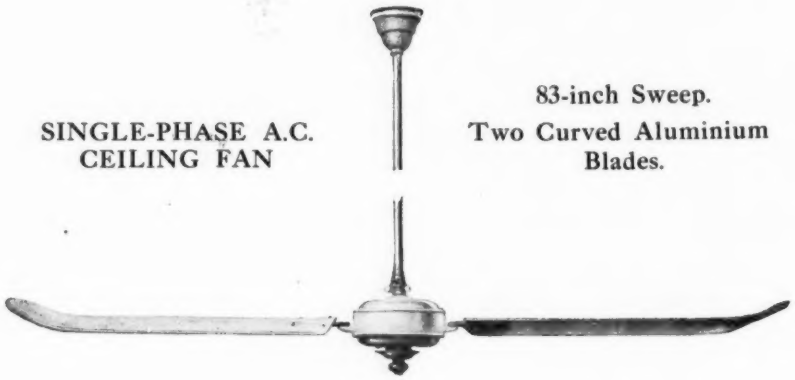

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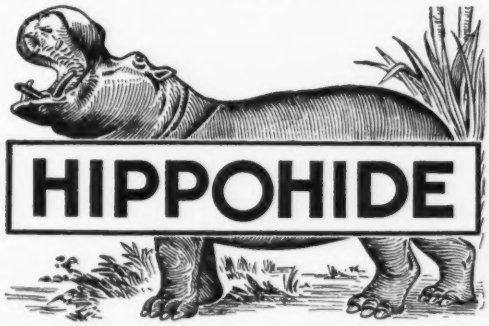

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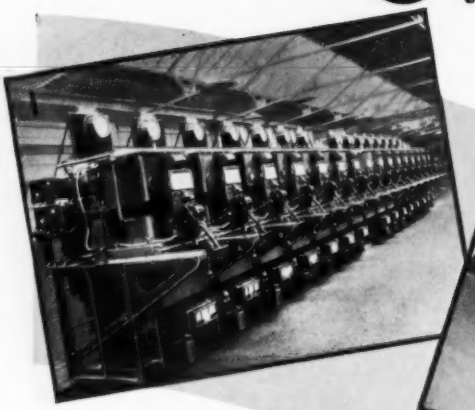

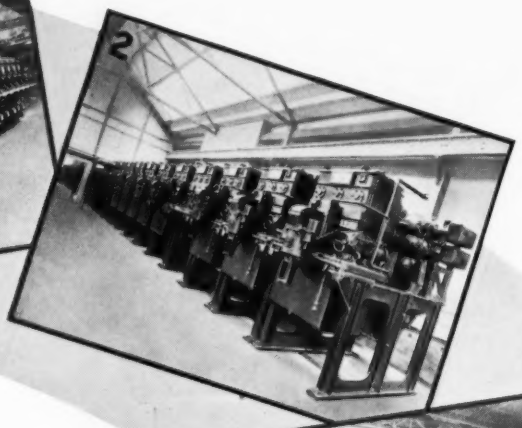

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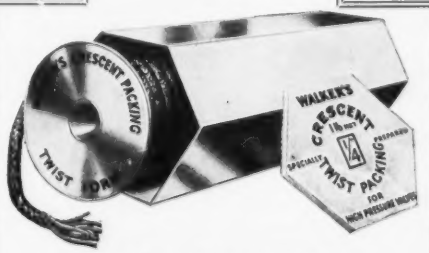

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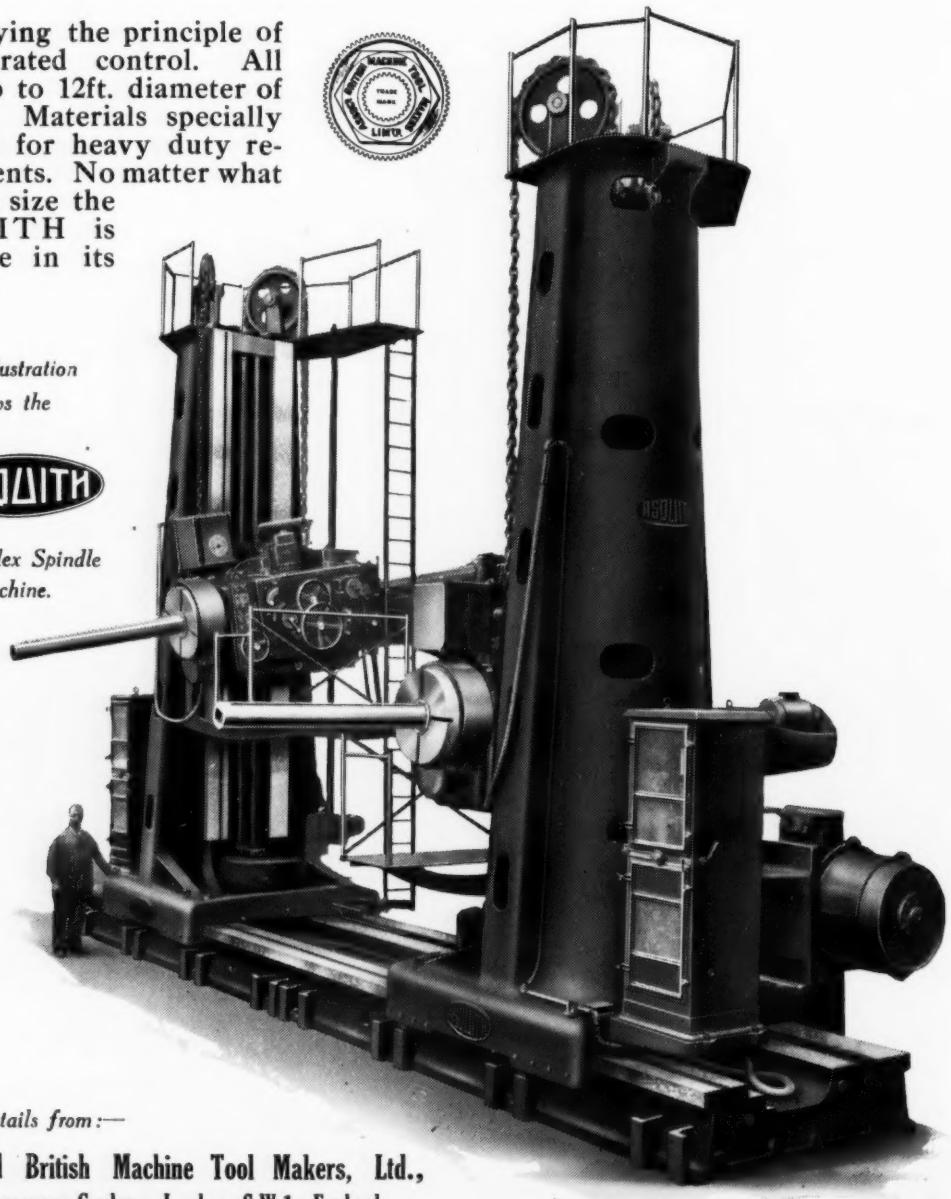

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